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PACIFIC COD (*GADUS MACROCEPHALUS*) STUDIES IN PORT TOWNSEND BAY, WASHINGTON

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William A. Karp and Bruce S. Miller

FINAL REPORT
December 1976 - August 1977
Contract No. N 68248-76-C-0006
UNITED STATES NAVY

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Robert L. Burgner, Director

Abstract

Egg, larval, juvenile, and adult stages of the Pacific cod (Gadus macrocephalus) were sampled from the waters of Port Townsend Bay, Washington, to provide information concerning the life history and fisheries biology of this species. Trawl sampling, carried out in January and February 1977, provided material for the determination of basic statistics, age structure, stomach contents, and fecundity. The trawl-caught fish were found to be fast growing, early maturing, and with short lifespans; estimated fecundity at length was greater than published values for populations from more northern waters. Preferred food items were shrimp and small fish. Ichthyoplankton sampling was carried out on seven occasions from February through June 1977. Gadoid (cod family) larvae were identified from many of the samples but poor documentation of the early life history of Pacific cod precluded positive identification of these gadoid larvae to species. It was suggested that gadoid larvae observed in late April were probably Pacific cod, based on spawning time and published rates of development. Attempts to rear Pacific cod eggs and larvae were not successful but the experiments did confirm reports that the eggs are demersal. Diving operations failed to encounter spawning adults or eggs. Eggs were not detected from a series of bottom grab samples. Juvenile Pacific cod were identified from trynet samples taken in northern Kilisut Harbor and along the northwest shore of Indian Island in mid-June 1977.

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1. Introduction

The Pacific cod (Gadus macrocephalus) is widely distributed in the North Pacific Ocean. In western North America this species is found in the southeastern Bering Sea and in the waters of the Aleutian Islands, along the Pacific coast of the Alaska Peninsula, and around the Gulf of Alaska, southwards to northern California (Hart, 1973).

Commercial fishing for Pacific cod does not occur south of Destruction Island on the Washington coast, although incidental cod catches are recorded for southern Washington and Oregon waters (Ketchen, 1961).

There is, however, a substantial commercial fishery for Pacific cod in Washington waters. Gosho (1976) reported that, between 1966 and 1973, cod was the second or third most important fish landed by trawlers in Washington State each year. The average annual catch during this period was 2.9 million kg and 28% of this catch was taken from the Washington waters of Puget Sound and the Gulf of Georgia. The major portion of this annual 0.7 to 1.1 million kg inside waters catch has been taken from the eastern Strait of Juan de Fuca.

The work of Ketchen (1961, 1964) provided a considerable amount of information on the biology of the Pacific cod in Canadian waters. He determined growth and mortality rates for trawl-caught fish, described seasonal movements, and discussed the present and future potential of the commercial fishery. Moiseev (1953) discussed in some detail the distribution, biology, and ecology of Pacific cod in Soviet waters of the Northwestern Pacific.

The work of Cobb (1927) and Alverson (1960) provided background on the Pacific cod fisheries of North American coastal waters. Gosho (1976) reported the results of tagging experiments carried out in Washington waters between 1966 and 1973; his data indicated that cod in Washington

waters consist of a number of small subpopulations which retain a high degree of isolation--fish tagged in the eastern Strait of Juan de Fuca were recovered in the area where they were released, often on the same fishing grounds. A very small proportion of the fish recaptured had migrated out of the area of recapture, indicating at least some exchange between stocks. Seasonal migrations have been observed in some areas. Adult Pacific cod are found in abundance in Port Townsend Bay, Washington, during their December to March spawning period; however, for the remainder of the year this stock is distributed over a wider area and densities in the bay are generally low.

A trawl fishery for Pacific cod has been carried out in this area since the 1920s and a set net fishery for the species was established in Port Townsend Bay in February 1975. Commercial fishing has taken place only during the spawning period. Annual Pacific cod landings for Port Townsend Bay have been on the order of 180,000 to 220,000 kg in recent years.

The spawning behavior and early life history of the Pacific cod in eastern Pacific waters are not well documented. Laboratory studies of the environmental requirements for early development have been carried out by Canadian workers (Forrester, 1964; Forrester and Alderdice, 1965; Alderdice and Forrester, 1971), and aspects of the early life history of the species have been documented for Russian (Mukhacheva and Zviagina, 1960) and Japanese (Yamamoto and Nishioka, 1952) waters. Thompson (1963) reported that Pacific cod in Canadian waters lay demersal eggs. This is consistent with the observations of Moiseev (1953) who also observed that the eggs are slightly adhesive in western Pacific fish.

Observations by Washington Department of Fisheries (WDF) and commercial fishermen indicate that the Port Townsend population may spawn in the vicinity of Walan Point, Indian Island (Fig. 1). In 1976, when the United States Navy published plans for the construction of an extensive munition dock complex in the Walan Point area, concern was expressed by WDF that such a development might influence the spawning and early survival of the cod.

This research project was established to determine as much as possible about the spawning behavior and early life history of the Pacific cod in Port Townsend Bay. Additional objectives were to examine other aspects of the biology of the Pacific cod and to assess the influence of the Walan Point development on the resource.

2. Methods and Materials

2.1 Trawl Surveys

Trawl surveys were carried out from the 19.8-m University of Washington research vessel COMMANDO in late January and mid-February. A commercial 400-mesh Eastern otter trawl, with forward, intermediate and cod-end sections of 10.2-cm, 10.2-cm, and 8.9-cm mesh construction, respectively, was used to sample adult cod on the commercial fishing ground in Port Townsend Bay (Fig. 1).

2.1.1 Basic Measurements

Pacific cod sampled in the trawl were measured for total length and weighed on a spring balance (to the nearest 100 gm) for total weight. Sex and maturity were determined after opening the body cavity. Scale, ovary, and stomach samples were removed from fish selected to represent the range of sizes observed in the catch.

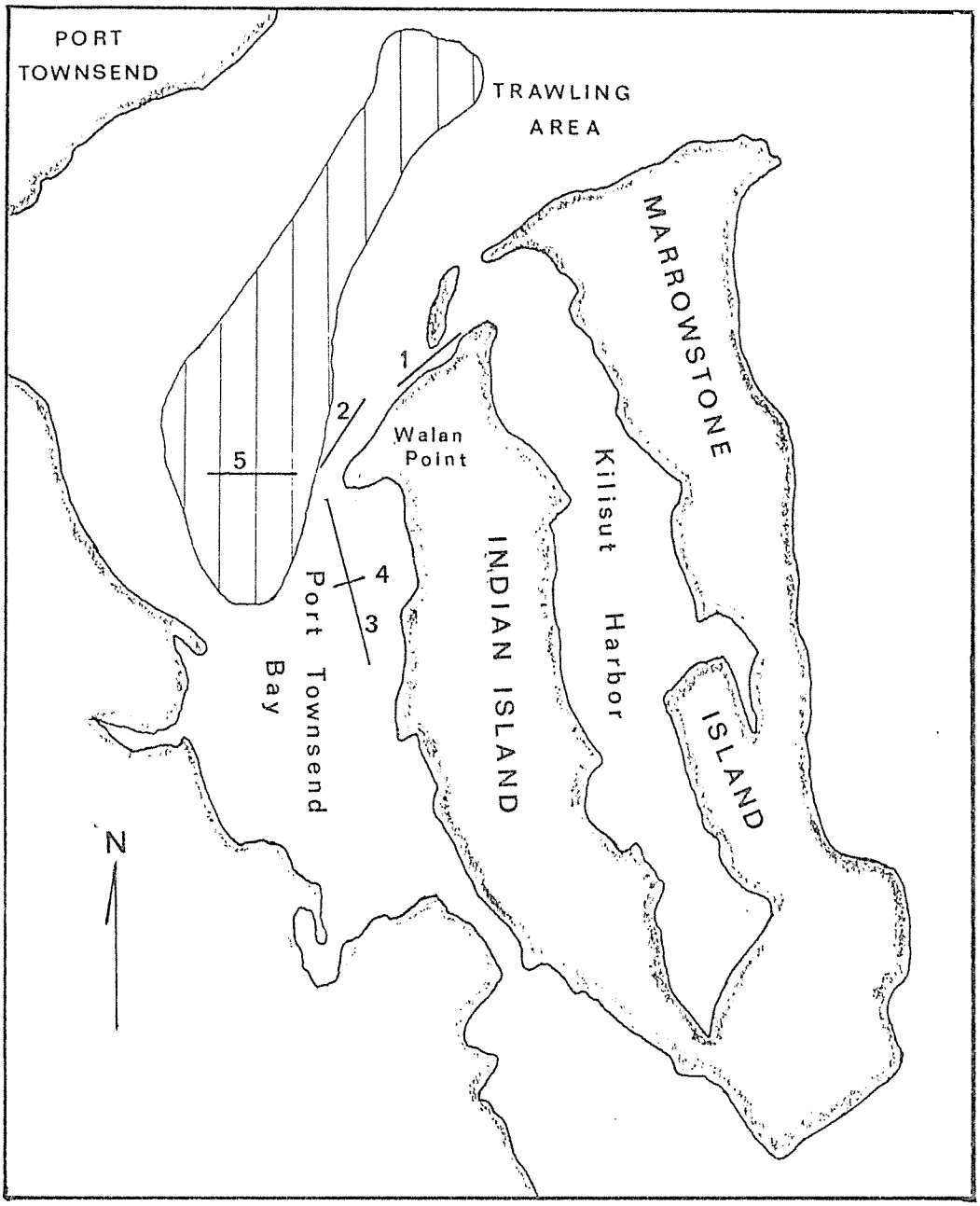


Fig. 1. Map of study area showing commercial trawl area and ichthyoplankton sampling transect stations.

2.1.2 Age and Growth

Length frequency histograms were prepared for all trawl-caught fish and for each sex to enable the size structure of the population to be analyzed. Length-weight relationships of the form

$$W = AL^B$$

linearized to

$$\ell n\ (W) = \ell n\ (A) + B\ \ell n\ (L)$$

where

W = weight in gm

L = total length in mm

A and B are constants

were developed to describe growth characteristics.

Scales were removed from the left side of the fish midway between the second dorsal fin and the lateral line. Several scales were removed with a spoon and the sample was then transferred to a labelled envelope. In the laboratory, scales were mounted in a weak detergent solution between two microscope slides. Scale annuli were counted with the aid of a GAF microfiche projector at 42X magnification according to the methods of Kennedy (1970).

Scale annuli were identified and the distance from the focus of the scale to each annulus was recorded. An incipient annulus was present at the edge of most scales; this is consistent with Kennedy's (1970) observation that cod growth in Hecate Strait ends in mid-October and resumes in April. Therefore, the scale edge was considered to be the annulus of the last year of growth of the fish.

A body length : scale width relationship was established using the model,

$$L = AS^B$$

linearized to

$$\ell n\ (L) = \ell n\ (A) + B\ \ell n\ (S)$$

where

L = total body length in mm

S = scale width in mm

A and B are constants

Von Bertalanffy growth curve parameters were estimated from the age data (Gulland, 1969). This relationship normally takes the form,

$$L_t = L_\infty(1 - e^{-K(t-t_o)})$$

where L_t = length at time t

L_∞ = asymptotic length when $t = \infty$

K describes the curve

t_o = theoretical time when L = 0

The traditional method of fitting observations to this model involves linearization according to the methods of Ford (1933) and Walford (1946). Non-linear techniques are more appropriate to the solution of the von Bertalanffy equation. Allen (1966) described a non-linear least squares method. The computational techniques of Somerton (1977) were used to process the data from this study.

Scales were also obtained from a sample of seven large adult cod caught in a commercial gill net. Data obtained from these scales were utilized in some of the analyses.

2.1.3 Stomach Content Analysis

Stomach contents were examined from a subsample of the fish obtained in the July trawl survey. Stomachs were first tied off at the esophagus, then cut above the tie and below the pyloric sphincter, and removed from the body cavity and preserved in 10% formalin. Samples were washed and soaked in fresh water before laboratory examination. The weight of each stomach was recorded after it had been blotted dry with a paper towel. The contents of each stomach were then removed and the empty stomach was weighed again to allow the weight of contents to be determined. A qualitative assessment of stomach fullness was made before each stomach was emptied--observations were recorded as "empty", "trace", "25% full", "50% full", "75% full", "full", or "distended". The volume of identifiable contents was recorded for each stomach and the stage of digestion was evaluated as "slight", "moderate", or "advanced". Stomach contents were identified into taxonomic groups and then the number of individuals in each taxon was counted, and the proportion of each taxon in the total identifiable stomach contents was estimated.

2.1.4 Fecundity Estimation

Mature female fish were selected from the catches for fecundity determination. Ovaries were carefully excised from the body cavity and placed in Gilson's fluid to facilitate separation of the ova from the ovarian tissue. In the laboratory, ovarian tissue was carefully removed from each sample. Subsamples of 1,000 or 2,000 eggs were counted out for each sample. The samples and subsamples were then heated to constant weight in an electric oven and fecundities were calculated by proportionality.

A length-fecundity relationship was established according to the technique used by Healey and Nicol (1975) and others who used an exponential model of the form,

$$F = AL^B$$

linearized to

$$\ell n\ (F) = \ell n\ (A) + B\ \ell n\ (L)$$

where F = fecundity

L = total length in mm

A and B are constants

2.2 Small-Boat Operations

Ichthyoplankton, trynet, and diving operations were carried out from the 11.3-m University of Washington research vessel MALKA.

2.2.1 Ichthyoplankton Surveys

A 60-cm aluminum bongo net array (Posgay, et al., 1968) was used for ichthyoplankton sampling. Nitex nets of 505-μ mesh were used on all occasions except on May 23 when one 333-μ net was used because of gear damage. Five ichthyoplankton sampling transect stations were established (Fig. 1).

Ichthyoplankton sampling was carried out on seven occasions from March 25, 1977, to June 14, 1977. Stations 1 and 3 (Fig. 1) were sampled on all seven sampling trips. Station 4 was sampled only on March 18 since it was decided that this station duplicated station 3 and it was discontinued. Station 5 was sampled on April 29 and May 23, when a little more boat time was available, to provide some data regarding the ichthyoplankton of central Port Townsend Bay. All ichthyoplankton sampling was carried out after dark.

Station 1 was in relatively shallow water where sampling was carried out at a fixed depth just below the surface. Oblique sampling hauls were

carried out at the other stations on each occasion except on the first sampling trip (25 February) when all samples were horizontal surface tows.

General Oceanics flowmeters were used to determine the volume of water filtered by each net haul. A bathykymnograph trace was obtained to record the path of the gear during each oblique haul.

Surface sampling was carried out by bringing the boat onto station, setting the engine speed to 600 rpm and lowering the gear just below the surface. Sampling duration was 5 or 10 min. Oblique sampling was carried out by releasing the gear as quickly as possible while moving forward at 600 rpm; either 30 or 45 m of cable were released, depending on bottom depth. The gear was then winched slowly to the surface while the boat maintained constant speed.

At the completion of each tow, the gear was hauled out of the water and carefully hosed down to concentrate organisms in the cod end buckets and prevent subsequent contamination. Plankton was stored in 1-liter glass jars and preserved with 5% buffered formalin. Flowmeter readings were recorded before and after each haul.

In the laboratory all samples were sorted under an illuminated magnifier. Fish eggs and larvae were removed and stored in 4-ml vials with 5% buffered formalin. The eggs and larvae were carefully examined under a stereo binocular microscope. Concentrations of eggs and larvae per cubic meter were calculated.

2.2.2 Trynet Sampling

The trynet, a small-scale otter trawl, was designed for towing with a single cable from a small boat.

It was 6.1-m long, 3.3-m wide, 0.76-m deep at the mouth, and made from green knotted and knotless nylon. The throat and body of the net

were made of 3.8-cm stretch mesh; the cod end, which was 1.8 m long, was made of 2.9-cm stretch mesh with a 0.64-cm stretch mesh liner (Harris and Hartt 1977).

Trynet sampling was carried out during some of the ichthyoplankton sampling cruises to provide supplementary data. Hauls were taken on the commercial fishery ground in about 27 m of water and along the shore of Indian Island, north and south of Walan Point in deep (18-27 m) and shallow (9-18 m) water (Fig. 2). On June 14 a trynet sample was taken in the northern part of Kilisut Harbor. All hauls were of 15-30 min. duration. Species lists were prepared and gadoids (i.e., fishes of the cod family) were enumerated from each catch.

2.2.3 Diving Operations

A series of eight SCUBA dives was made in the study area. During six of these dives the dock construction area was surveyed--these dives were carried out on January 16, February 5, February 25, March 5 (two dives), and March 18 (at night). Two dives were made in the entrance to Kilisut Harbor, close to ichthyoplankton station 1 (Fig. 1).

Five of the survey dives (including the night dive) consisted of 30-45 min. of slow swimming in a zigzag fashion across the dock construction area from about a 5-m bottom depth to a 20-m depth and then back to 5 m, continuing until the air supply ran out. One dive consisted of surveying in the same manner but from the shoreline to about a 10-m water depth.

One of the dives (February 25) at the Kilisut Harbor entrance covered the approximate area indicated by station 1 (Fig. 1). The other dive (March 5), in the same general area, consisted of swimming slowly along a commercial set net near the shoreline of Indian Island.

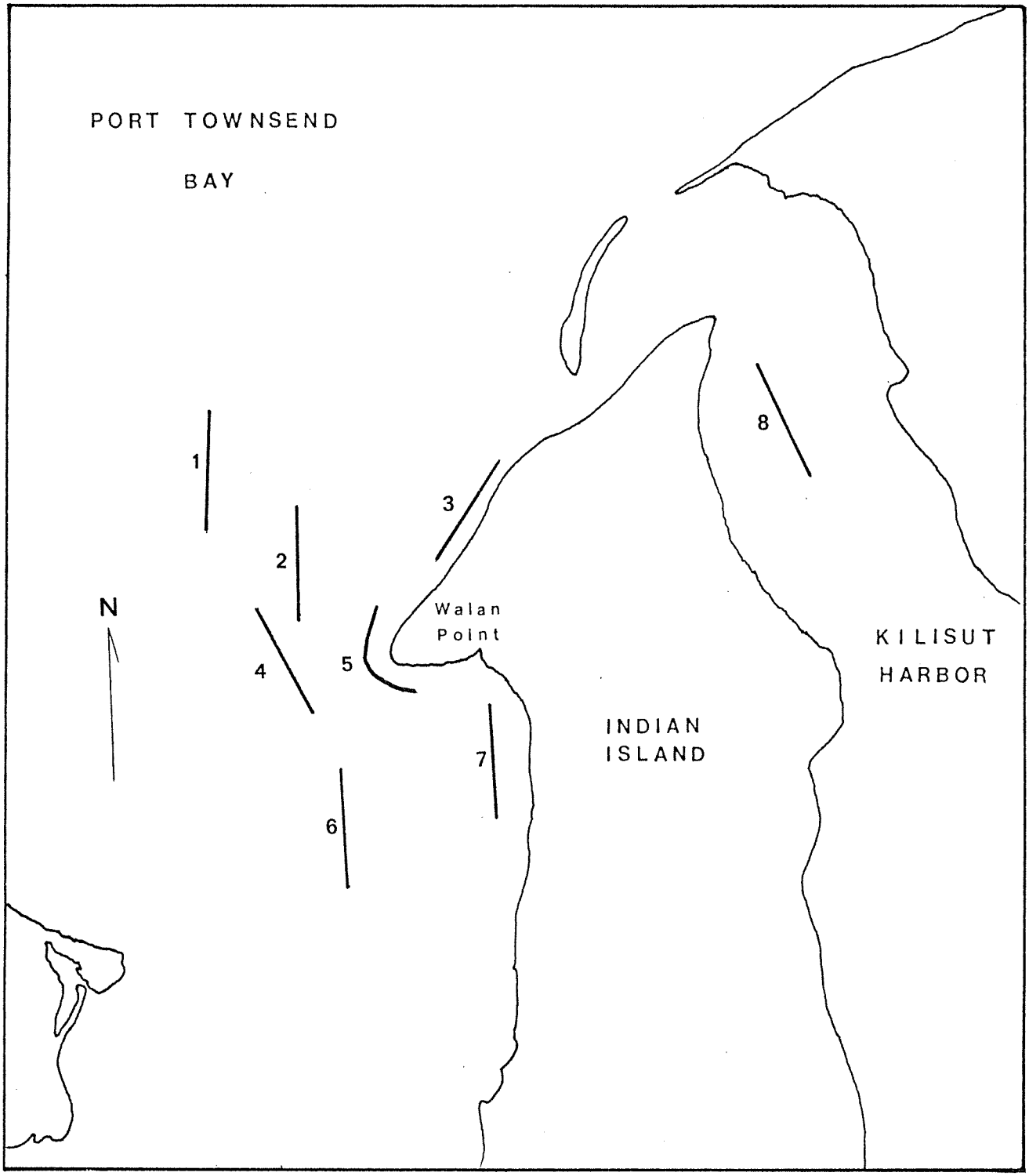


Fig. 2. Map of study area showing trynet sampling locations.

2.2.4 Substrate Sampling

The eggs of Pacific cod are widely reported to be demersal. As part of the search for these eggs in the study area, extensive bottom grab sampling was carried out at the Walan Point docksite with a 1/10-m^3 Van Veen grab in early March. Two transects were sampled at 2- or 4-m depth increments. Eleven samples were taken and examined for the presence of fish eggs and for substrate characteristics.

2.3 Documentation of Early Life History

Laboratory rearing experiments were attempted on two occasions. Commercially caught ripe male and female cod were artificially spawned at Port Townsend and the eggs were transported to Seattle for rearing. Development of the eggs was observed for seven days on the first occasion before equipment failure caused total mortality. On the second occasion, technical problems with the rearing equipment again forced early termination of the experiment.

3. Results

3.1 Trawl Surveys

3.1.1 Catch Statistics

A total of 569 Pacific cod were caught during the trawl surveys in January and February (Table 1). The catch per unit of effort was greater both in biomass and numbers in February than in January. Similar trends were observed in the commercial fishery. Trawl-caught fish averaged 451 mm in length and 1,000 g in weight in the January catches and 457 mm in length and 1,000 g in weight in the February catches. The average length of females was greater than the average length of males in all catches except haul 2 of February 15, which was the only nighttime sample.

Table 1. Trawl data summary.

Date	Haul No.	Sexed males N	Sexed males Mean length (mm)	Sexed males Mean weight (gm)	Sexed females N	Sexed females Mean length (mm)	Sexed females Mean weight (gm)	All fish N	All fish Mean length (mm)	All fish Mean weight (gm)	Total weight (gm,lbs)	Effort (min)
25 Jan	1	26	387	960	24	493	1090	50	438	1020	51,300 (113)	40
25 Jan	2	14[a]			9	454	1020	23			23,500 (52)	30
27 Jan	1	10	450	880	17	453	990	27	452	950[b]	24,700 (54)	60
27 Jan	2	8	452	870	13	477	1070	21	467	990	20,950 (46)	60
28 Jan	1	15	452	970	21	461	1120	36	457	1060[c]	37,150 (82)	60
Jan. summary		73	423	940	84	470	970	157	451	960	157,600 (347)	250
15 Feb	1	104	445	960	75	466	1140	180	454	1030	186,100 (410)	60
15 Feb	2	25	461	1110	19	440	900	45	451	1020	45,900 (101)	30
15 Feb	2[d]	12	249	150	24	253	170	36	252	160	5,820 (13)	
16 Feb	1	76	455	980	74	467	1070	150	461	1020	153,700 (339)	30
Feb. summary		205	451	980	168	464	1080	375	457	1030	385,700 (850)	120

[a]Males not weighed or measured, total weight extrapolated.
[b]Weight for 26 fish.
[c]Weight for 35 fish.
[d]Juveniles from haul 2--data not included in other computations.

This was also the only haul in which a large number of juvenile cod were taken. There were fewer males than females (73:84) in the January catches, and more males than females (205:168) in the February catches. Most fish were either mature or ripe; a small number of spent females were observed in the February catches.

3.1.2 Age and Growth

Length frequency histograms were prepared for all the trawl-caught fish (Fig. 3). Two modes were detected in each histogram. The first mode, from 200 to 300 mm, represented the juvenile fish. The second mode, from about 350 mm to 650 mm, represented mature adult fish available to the commercial fishery. This mode was skewed toward smaller fish for the males but was relatively symmetrical in form for the females. All the length frequency histograms demonstrate the comparatively low abundance of larger fish, particularly those of total length greater than 550 mm.

Weight-length relationships were determined independently for males, females, and all trawl-caught fish (Table 2). The relationships were also plotted (Fig. 4). Estimated weights at length for females were greater than for males, until a length of about 485 mm when the calculated weight at length began to be greater for males than for females. Many of the female fish were highly gravid and a few were spent; no correction was made for these conditions.

Age was determined for 272 fish. Body-length : scale-width relationships were determined independently for males, females, and all fish (Table 3) and the results plotted (Fig. 5). Relationships were similar in all cases. The "all fish" category included a small sample of large unsexed fish from the commercial set net fishery. Age group characteristics for the aged fish were also calculated (Table 4). Most

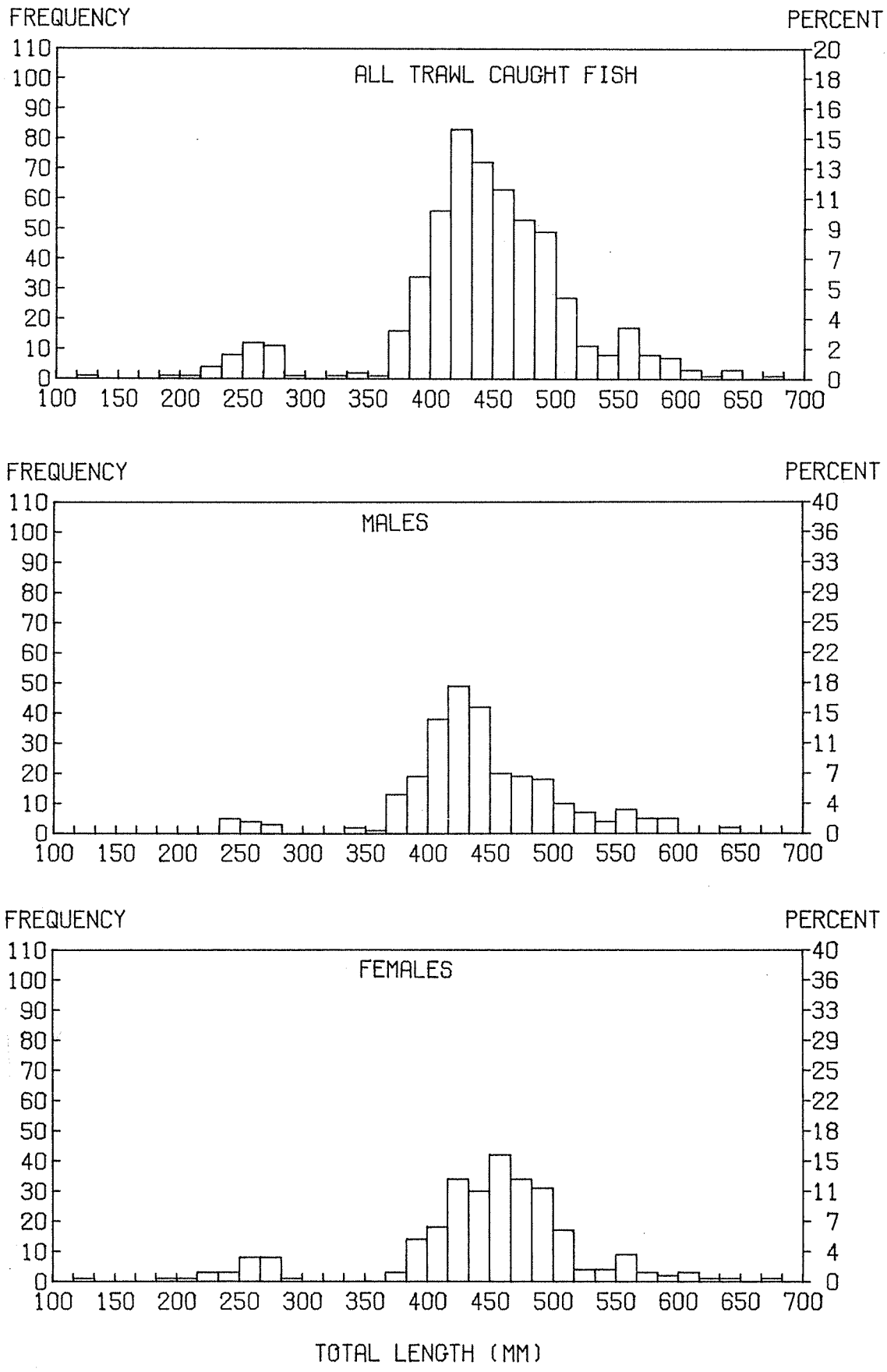
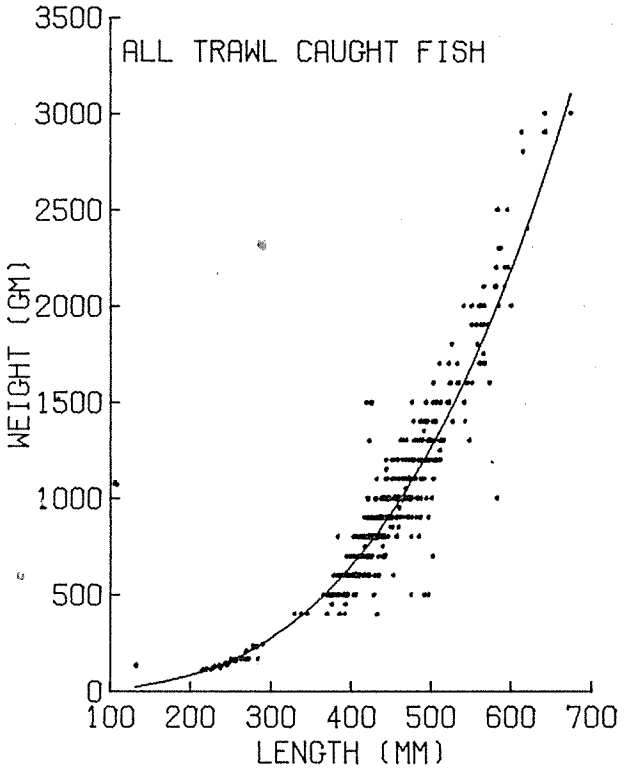
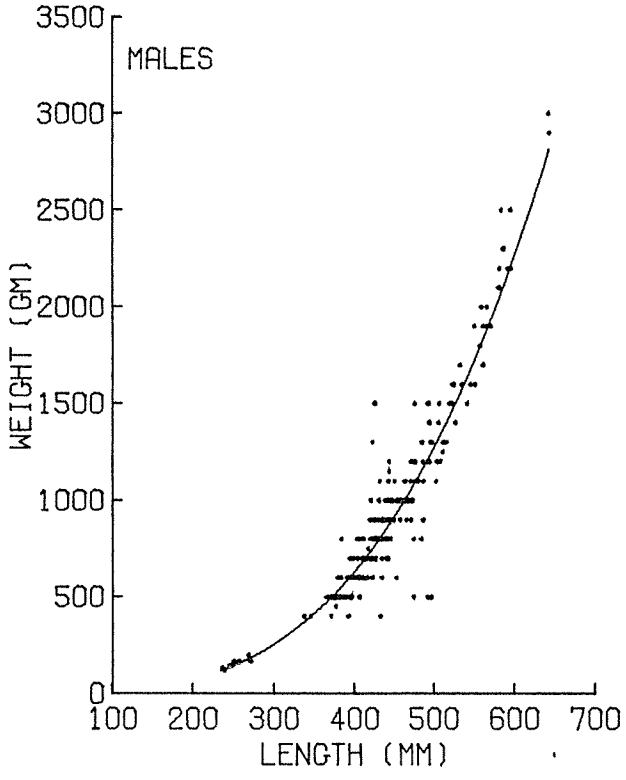


Fig. 3. Length frequency histograms for trawl catches.

Table 2. Weight-length relationships of the form weight = A (length)^B for trawl-caught cod.

	Constant (A)	Exponent (B)	Correlation coefficient (R^2)	Sample size
Males	0.0000041	3.1447	0.899	274
Females	0.0000187	2.9009	0.915	275
All fish	0.0000106	2.9919	0.909	553





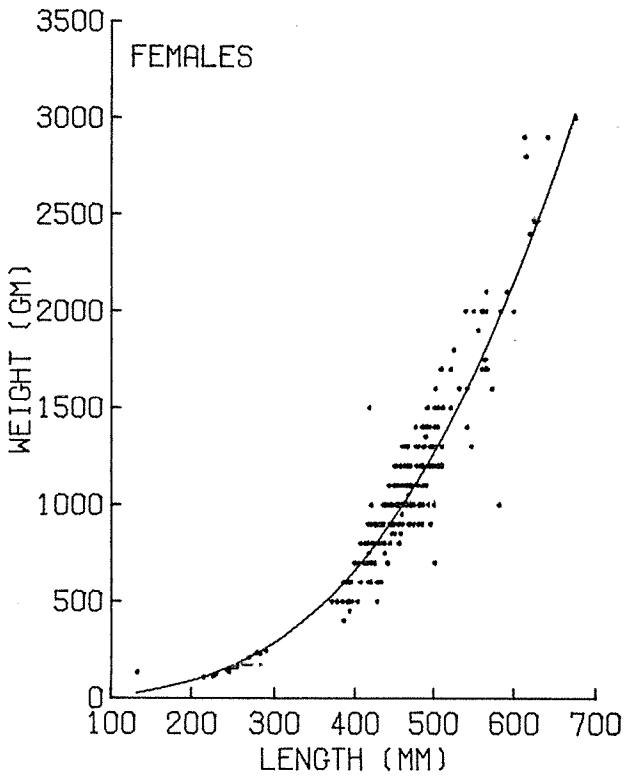


Fig. 4. Length-weight relationships for trawl catches.

Table 3. Body-length : scale-width relationships of the form length = A (scale width)^B

	Constant (A)	Exponent (B)	Correlation coefficient (R^2)	Sample size
Males	301.39	0.6784	0.676	120
Females	290.15	0.8450	0.645	138
All fish*	294.12	0.7021	0.672	272

*Includes 7 set net fish.

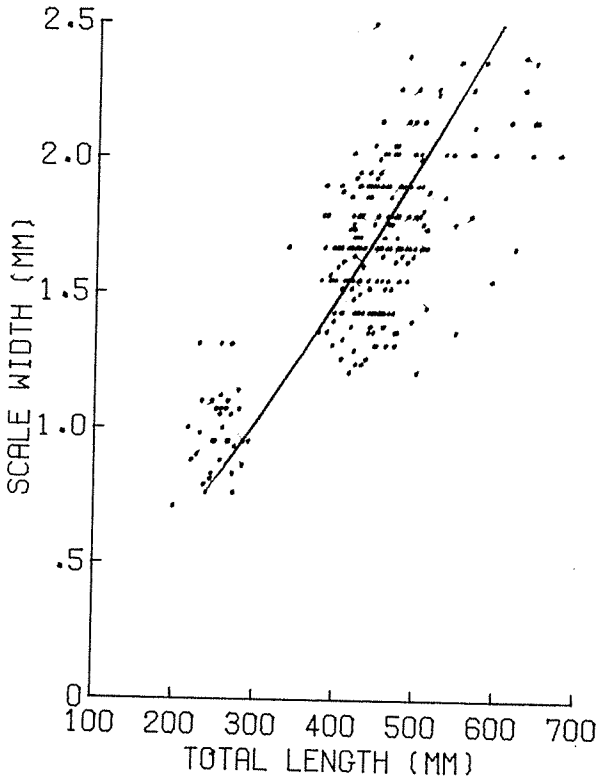


Fig. 5. Scale-width : body-length relationship for trawl and set net catches.

Table 4. Age group characteristics.

Sex	Age (yrs)	Mean length (mm)	Variance	Range (mm)	Min. (mm)	Max. (mm)	Sample size
Male	1	250.5	217.1	51	220	271	13
Male	2	427.0	878.0	121	376	497	51
Male	3	458.7	1636.1	163	382	545	55
Male	4	566.0			566	566	1
Female	1	257.6	794.5	140	197	337	26
Female	2	441.4	984.4	124	385	509	63
Female	3	480.4	3259.7	289	356	675	49
All fish*	1	255.2	602.6	140	197	337	39
All fish*	2	435.0	980.0	133	376	509	114
All fish*	3	473.8	3104.4	293	382	675	109
All fish*	4	602.3	1658.3	96	550	646	9
All fish*	5	720.0			720	720	1

*Includes unsexed trawled fish and larger set net fish.

of the fish examined were two or three years old. None of the females were greater than three years old. One trawl-caught male was four years old. The set net fish contributed one five-year-old and six four-year-old fish to the analysis. The largest number of males aged were three years old and the largest number of females aged were two years old. Samples for age determination were selected at random from the trawl catches and it was assumed that these age data were consistent for the total catch.

Von Bertalanffy growth curve parameters were determined for males, females, and all fish (Table 5). The paucity of data for fish of four and five years of age introduced a bias into the computations. The most realistic estimates were for all the trawl-caught fish with the addition of the seven larger set net fish where

$$L_t = 530\ (1 - e^{-0.95(t-0.29)})$$

(Fig. 6).

3.1.3 Stomach Content Analysis

Stomach contents were determined for 106 fish from the January trawl survey and were evaluated as the percentage frequency of occurrence of the major food categories by sex and time of day (Table 6, Fig. 7). Shrimp constituted the most frequently encountered food item for both sexes at all times of the day. Small fish (cottids or juvenile herring) were the next most important food item in all categories except for females from the evening trawl sample; mysids were the second most frequently encountered food item in this category; and small fish were ranked third. Mysids were the third most frequently encountered food item in all other categories. In general, a very small proportion of the stomachs examined was empty. Twenty-five percent of the female fish examined from the evening trawl

Table 5. Von Bertalanffy growth curve parameters.

	L_∞ (mm)	K	t_o (years)	Sample size
Males	470	1.60	0.53	120
Females	490	1.50	0.51	138
All trawl-caught fish	500	1.30	0.44	265
All fish*	530	0.95	0.29	272

*Includes 7 set net fish.

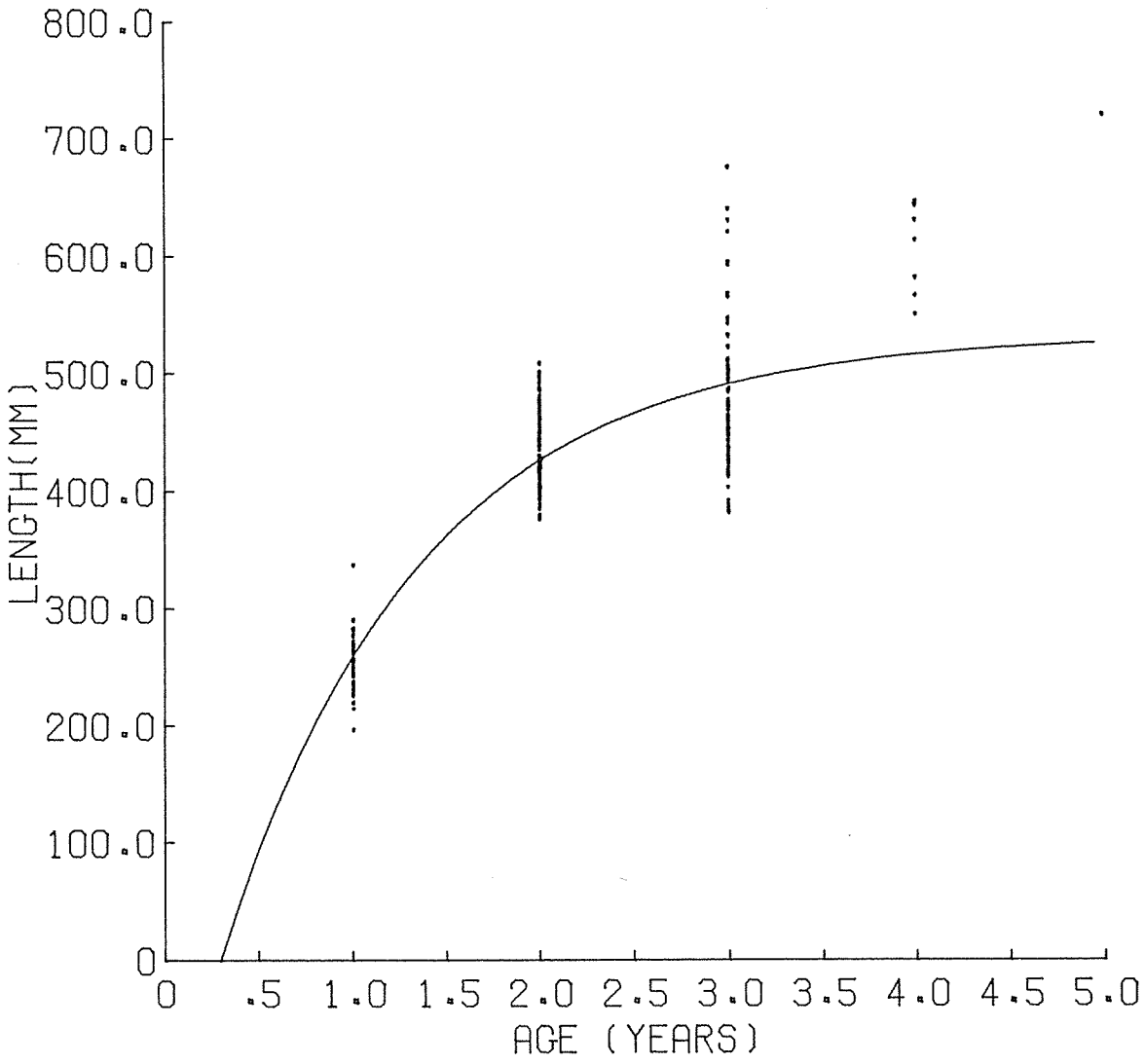


Fig. 6. Von Bertalanffy growth curve for trawl and set net catches.

Table 6. Percentage frequency of occurrence of major food categories by sex and time of day.

	Morning			Afternoon			Evening			Total		
	Male	Female	All	Male	Female	All	Male	Female	All	M	F	A
No. of fish:	15	20	35	28	32	60	3	8	11	46	60	106
Shrimp	87	75	80	82	88	85	100	63	73	85	80	82
Fish	40	30	34	21	16	18	67	25	45	30	22	26
Mysids	27	15	20	21	9	15	33	38	36	24	15	19
Empty	7	0	3	4	13	8	0	25	18	4	10	8

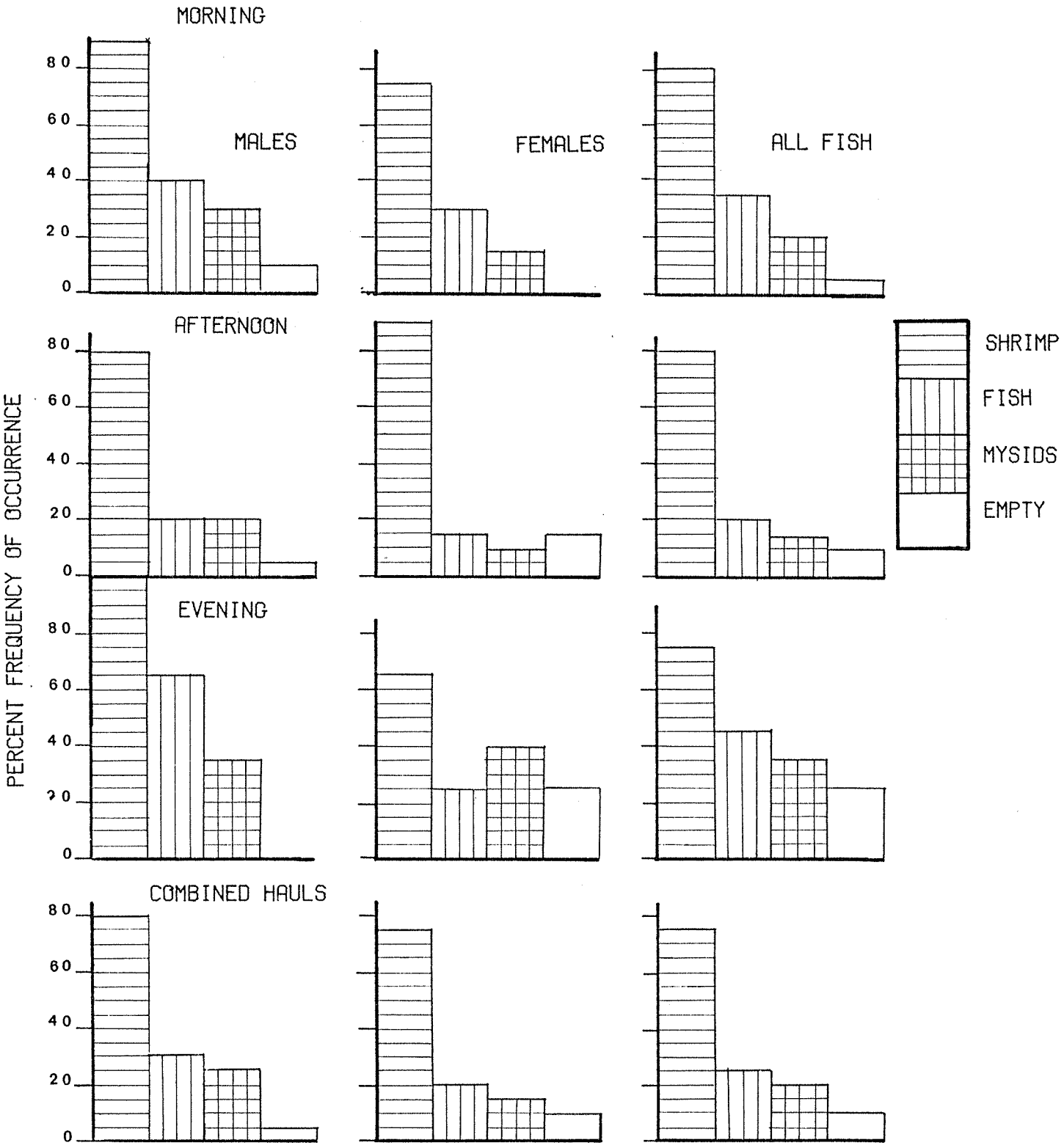


Fig. 7. Frequency of occurrence of major food categories by sex and time of day.

sample had empty stomachs but only eight females were examined from this sample. Stomach contents from fish caught in the morning were approximately equally categorized as advanced, moderately, or slightly digested. Most of the stomachs from afternoon and evening caught fish revealed an advanced or moderate degree of digestion.

3.1.4 Fecundity Estimation

Fecundity was determined for 40 fish. The relationship calculated was:

$$\text{Fecundity} = (0.001329)(\text{Total Length}^{(3.3340)})$$

$R^2 = 0.638$.

Calculated estimates of fecundity for females of 400, 500, and 600 mm total length were 629,000; 1,324,000; and 2,432,000 eggs per female, respectively (Fig. 8). The small number of fecundity determinations carried out for larger fish limits the reliability of this relationship.

3.2 Small-Boat Surveys

3.2.1 Ichthyoplankton Surveys

Ichthyoplankton catches were summarized (Table 7) and plotted (Fig. 9) for each sample. Some larvae were tentatively identified as young Pacific cod but were presented in the results section as gadoid larvae because of the difficulties of definitively separating the early life history stages of Pacific cod, tomcod (Microgadus proximus), and walleye pollock (Theragra chalcogramma). The highest abundances of fish eggs were observed at most stations on February 25. Station 1 (Fig. 1) produced the highest count, which was 1,059 eggs per 100 cubic meters. The estimated abundance of fish eggs was highest at station 1 on all occasions except April 15 and June 14. While trends and changes in estimated abundances of fish eggs were similar at stations 1, 2, and 3, the actual abundance estimates were

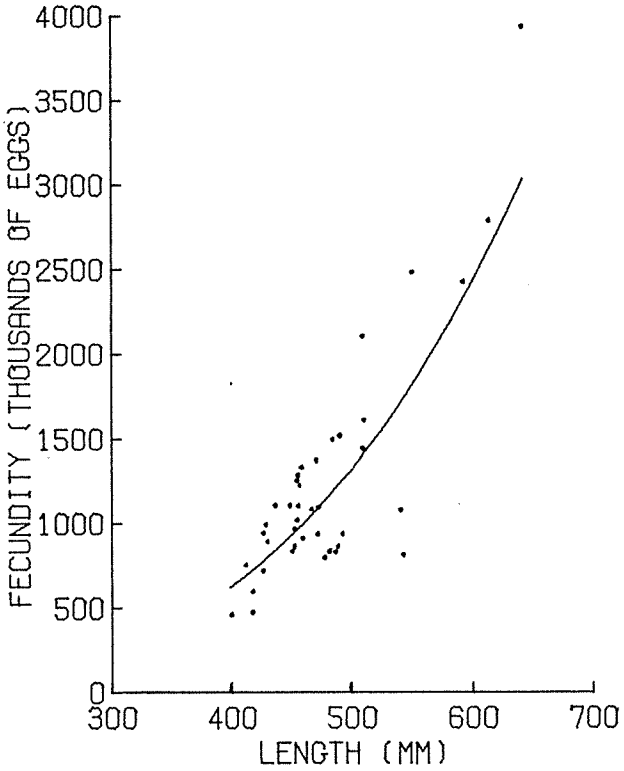


Fig. 8. Length-fecundity relationship.

Table 7. Ichthyoplankton catch summary.

Date	Station	Volume filtered (m^3)	Number of eggs per 100 m^3	Number of larvae per 100 m^3	Number of gadoid larvae per 100 m^3	Haul type
25 Feb. 77	1	426.3	1059.4	9.4	1.6	Surface
"	2	368.9	779.1	182.4	0.5	"
"	3	211.0	75.4	5.7	0.5	"
5 March 77	1	205.3	289.6	172.7	0.0	Surface
"	2	64.3	63.6	78.2	0.0	Oblique
"	3	338.0	77.8	30.5	0.3	"
18 March 77	1	218.9	249.0	278.2	0.9	Surface
"	2	55.0	105.3	39.5	3.29	Oblique
"	3	92.6	41.0	8.6	0.0	"
"	4	247.6	44.8	16.2	0.0	"
"	3 + 4	340.2	43.8	14.11	0.0	"
15 April 77	1	584.8	56.8	6.8	1.0	Surface
"	2	285.3	81.3	30.8	2.1	Oblique
"	3	373.5	33.7	11.2	1.3	"
29 April 77	1	310.7	36.4	6.1	1.0	Surface
"	2	128.7	12.4	62.2	12.4	Oblique
"	3	133.6	14.2	16.5	4.5	"
"	5	372.5	20.1	70.1	29.8	"
23 May 77	1	155.4	21.2	8.4	0	Surface
"	2	167.6	1.2	17.9	3.0	Oblique
"	3	398.5	1.0	13.3	1.3	"
"	5	192.6	8.3	35.8	5.2	"
14 June 77	1	156.5	3.2	0.6	0	Surface*
"	3	406.9	5.9	1.0	0	Oblique

*Volume filtered was estimated due to flowmeter malfunction.

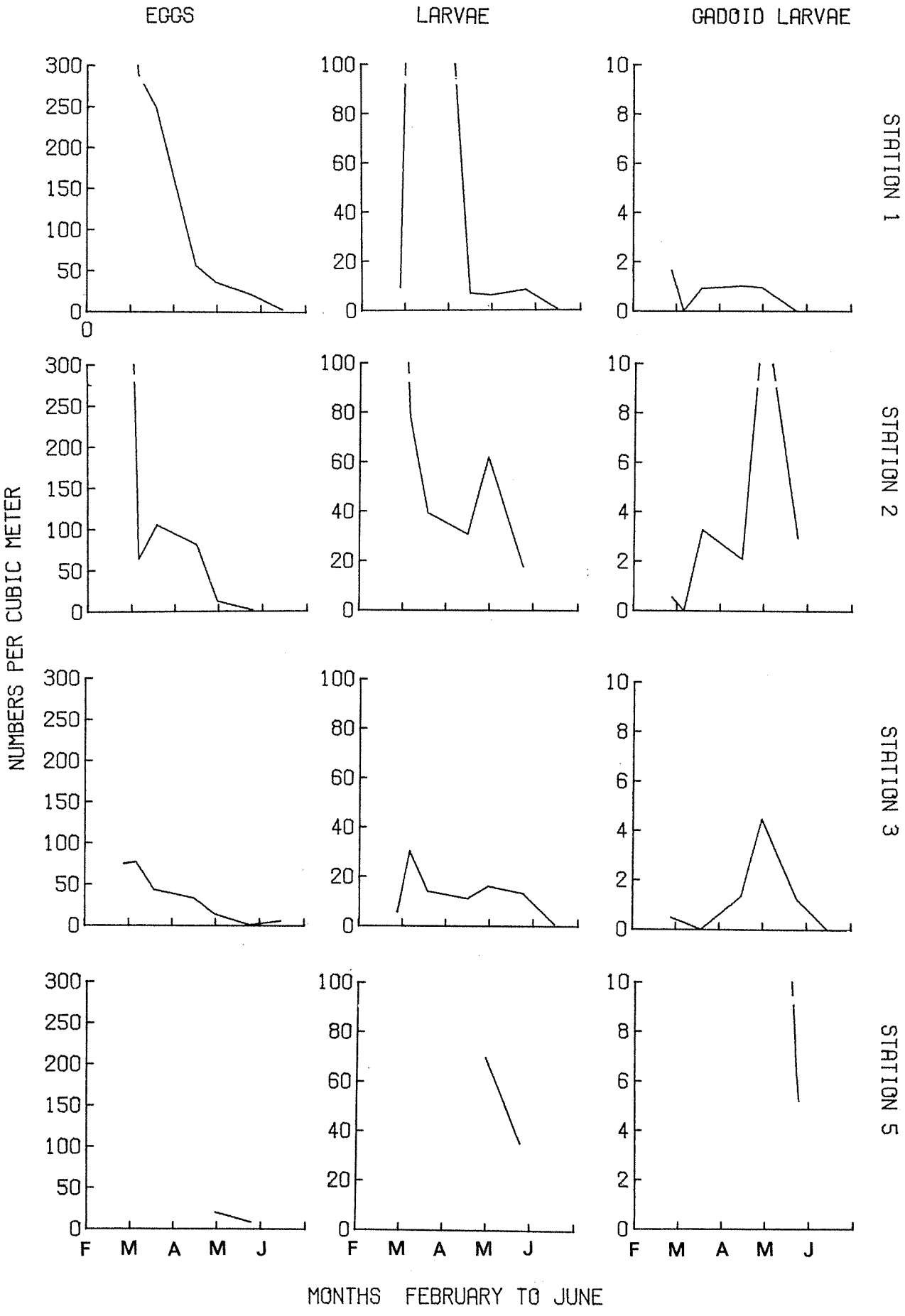


Fig. 9. Ichthyoplankton catches by station and month.

always considerably lower at station 3 than at stations 1 and 2. It should be stressed, however, that station 1 samples are not totally comparable with samples from the other stations because of differences in haul type (Table 7). A general trend of decreasing fish egg abundance with time was apparent from the data (Fig. 9).

Estimated abundance of fish larvae was greatest at station 1 on March 18, at station 2 on February 25, and at station 3 on March 5. After this peak, larval abundance decreased through the sampling period at all stations except for peaks at stations 2 and 3 on April 24, which correlate with increased counts of gadoid larvae from the samples at those stations and an uncorrelated small peak at station 1 on May 23.

The two samples from station 5 showed parallel trends in abundance of total fish larvae and gadoid larvae. Station 5 yielded the highest estimate of gadoid larval abundance of the study on April 24 (29.8 per 100 cubic meters) and also produced the highest total larval count for that sampling day. The estimated abundances of total larvae and gadoid larvae at station 5 on May 29 were both higher than at the other stations.

Gadoid larvae reached maximum abundance at stations 2, 3, and 5 on April 29, but a peak abundance was observed at station 2 on March 18. Station 1 generally demonstrated a low abundance of gadoid larvae. Abundance at stations 2 and 5 was relatively high during the peak period while abundance at station 3 was generally intermediate.

3.2.2 Trynet Sampling

Eight trynet sampling station-transects were observed during the study (Fig. 2). However, not all stations were sampled on each sampling trip (Table 8).

Table 8. Trynet sampling data summary.

Station: / Date	1	2	3	4	5	6	7	8
15 Apr 77		Sampled 1 young adult cod		Sampled no cod				
29 Apr 77			Sampled no cod		Sampled no cod	Sampled no cod		
23 May 77		Sampled no cod				Sampled no cod	Sampled no cod	
14 June 77*	Sampled 2 adult cod, no juvs.	Sampled no cod	Sampled 1 juv.			Sampled no cod	Sampled 5 juvs.	Sampled 74 juvs.

*See Table 9 for summary of juvenile gadoid catches.

On April 15 one young adult cod was taken at station 2. On June 14 two adult cod were taken at station 1. Juvenile gadoids were taken at all stations sampled on June 14 (Table 9). Juvenile Pacific cod were positively identified from the samples taken at stations 3, 7, and 8 (Table 9). Particularly noteworthy is the large catch of juvenile Pacific cod at station 8. These juvenile cod ranged in size from 30 to 93 mm total length with the greatest frequency between about 40 and 50 mm total length (Fig. 10). Since all juveniles were caught in June, they were estimated to be about two to three months old.

3.2.3 Diving Operations

No cod eggs were observed during any of the dives. Great care was taken to inspect the various sediment types encountered.

Two juvenile Pacific cod were observed during the night dive of March 18. A ripe and running female was observed in a set net at the entrance to Kilisut Harbor on March 5. No other adult cod were observed during diving operations.

Other fish seen during diving in the area of the proposed munitions dock were ratfish, big skate, cabezon, staghorn sculpin, tubesnout, English sole, rock sole, starry flounder, shiner perch, and midshipman.

3.2.4 Substrate Sampling

Eleven grab samples were taken on March 5. Bottom type was fine mud in all samples. Cod eggs were not detected in any sample.

4. Discussion and Conclusions

Most of the fish caught by the trawl were relatively small in size. The length-frequency distributions presented by Ketchen (1961) demonstrated that larger fish were available to the commercial trawl fishery on the

Table 9. Summary of juvenile gadoid catches from the trynet survey of June 14, 1977.

Sta. No.	Total No. of juvenile gadoids	Max. length (mm)	Min. length (mm)	Mean length (mm)	Variance	Number of juveniles identified as Pacific cod	Max. length (mm)	Min. length (mm)	Mean length (mm)	Variance	Haul duration (mins)
1	2	36.0	44.0	40.0	32.00	0					30
2	2	25.0	24.0	24.5	0.50	0					30
3	1	74.0	74.0	74.0		1	74.0	74.0	74.0		20
6	4	40.0	27.0	33.5	28.25	0					30
7	14	79.0	34.0	40.9	134.99	5	79.0	34.0	46.0	355.50	20
8	74	93.0	30.0	51.8	229.34	74	93.0	30.0	51.8	229.34	30

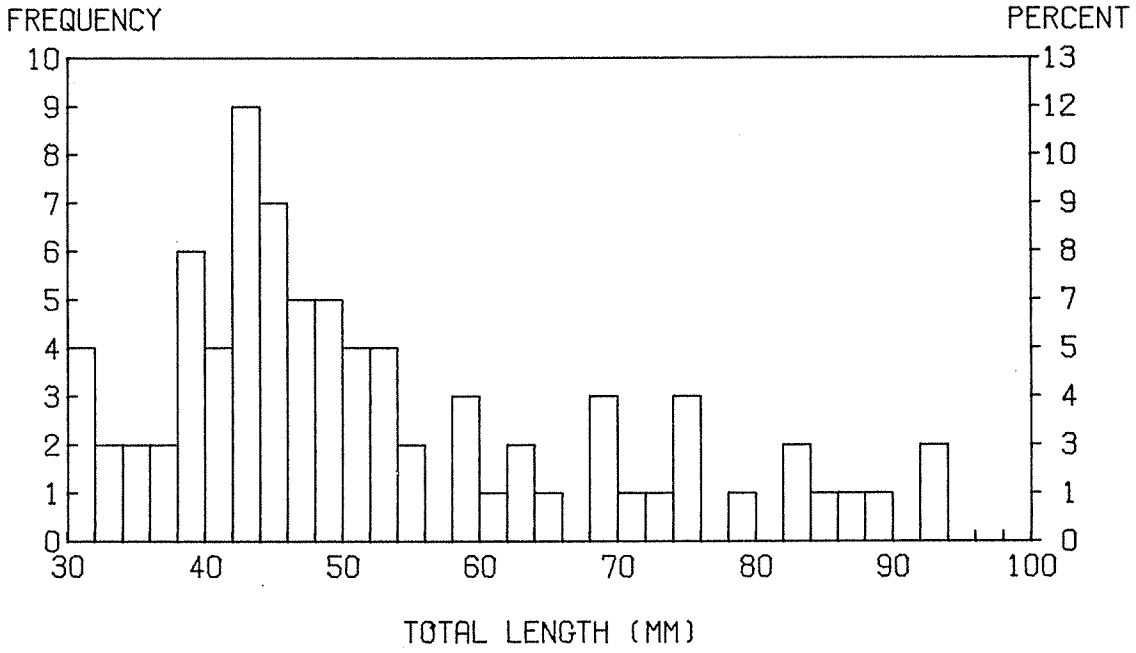


Fig. 10. Length frequency histogram for trynet catches of juvenile Pacific cod on June 14, 1977.

lower east coast of Vancouver Island. The set net fishery in Port Townsend Bay consistently landed cod of greater average length than the trawl fishery. This indicates that only a limited proportion of the spawning population of Pacific cod in Port Townsend Bay was available to the trawl fishery. The age structure of the trawl catches provides support for this argument; most of the male fish aged were two or three years old, and the peak age was three; none of the females aged were older than three, and the peak age was two. Four- and five-year-old Pacific cod were taken from the commercial set net fishery. Kennedy (1970) found Pacific cod up to seven years old in the trawl fishery of Hecate Strait, British Columbia. Larger and older fish were also frequently obtained from the colder waters of the Northwestern Pacific (Moiseev, 1953).

Almost all of the fish examined from the trawl catches were sexually mature. Thus, it appears that the Port Townsend trawl fishery has been largely supported by two- and three-year-old recruits, many of which reach sexual maturity at the time they enter the fishery. The older fish seemed to be unavailable to the trawl fishery, either by net avoidance or differences in location. These older fish were available, however, to the newly established set net fishery along the northwest shore of Indian Island.

The observed growth rates of the Port Townsend Pacific cod were high. This pattern is consistent with that expected from a boreal species close to the southern limit of its range. In these relatively warm waters Pacific cod grow faster, mature earlier, and live shorter lives than in the colder northern waters. Most of the females in the Port Townsend population of Pacific cod were mature at two years old (440 mm), compared with a 50% maturity at 550 mm for Hecate Strait fish (Thompson,

1962) and a 50% maturity at 690 cm for western Kamchatka fish (Moiseev, 1953).

The von Bertalanffy growth curve calculated from the data described a fast-growing population of small average size. It would be unwise to consider the parameters obtained by this technique more seriously until further length at age observations are available.

The stomach content analysis work indicated that shrimp and small fish were preferred food items. The work of Hart (1949) in British Columbia coastal waters supports these observations. Suyehiro (1934) also found crustaceans to be the most predominant food item present in summer-caught Bristol Bay cod stomachs. Moiseev (1953), however, reported that Pacific cod prefer small schooling fish, such as herring, for their prey and provided data from two studies to support this statement. Little is known of the availability of food organisms in Port Townsend Bay, and thus, it was not possible to determine whether the Pacific cod in the bay were able to locate their preferred food items.

Thompson (1962) determined a length-fecundity relationship for Hecate Strait, British Columbia, Pacific cod which converts to

$$\text{Fecundity} = (0.0000902)(\text{total length}^{(3.6415)})$$

which compares with:

$$\text{Fecundity} = (0.001329)(\text{total length}^{(3.3340)})$$

for this study. For the range of sizes examined, the Port Townsend cod population appears to have a considerably higher fecundity than the Hecate Strait population. A 470-mm female would be predicted to have 1,077,000 eggs in the Port Townsend population and 485,000 in the Hecate Strait population; a 550-mm female would have 1,819,000 and 860,000 eggs, respectively.

This high fecundity, as an adaptation to warmer waters, was observed by Moiseev (1953). Ketchen (1961) calculated that 1,000 mature cod from west Kamchatka (modal length about 800 cm) would produce approximately 2.93×10^9 eggs. Thompson calculated that 1,000 mature cod from Hecate Strait (modal length about 600 cm) would produce approximately 1.38×10^9 eggs (his calculation is in error, it should read 1.18×10^9 eggs). Using the modal length of 420 mm obtained from the Port Townsend trawl catches, the egg production for 1,000 mature females would be approximately 0.740×10^9 eggs. This mode would be much greater if set net catches were evaluated; if a mode of 475 mm is used the estimated egg production is 1.12×10^9.

The ichthyoplankton data provided some insight regarding the importance of the study areas as spawning and rearing sites for fish. The very high abundance of eggs and larvae at the southern approach to Kilisut Harbor (station 1) indicated that the harbor was probably an important rearing area for a number of species of fish. Many of the larvae sampled in March and April were baitfish species and a substantial spawning of Pacific herring has taken place in southern Kilisut Harbor for many years.

The abundance of eggs and larvae at station 2 showed similar patterns to those observed at station 1; the peak abundance of larvae occurred slightly earlier at station 2 than station 1, perhaps because of differences in species contribution. It appears likely that during an ebb tide plankton that passes over station 1 will be transported into the vicinity of station 2. The observed abundances of fish eggs and larvae were lower at station 3 than elsewhere, possibly because of a higher degree of mixing with the waters of the bay.

It is probable that the gadoid larvae identified from the February and March samples were not Pacific cod larvae. This is based on the observation that very few of the adult fish taken in the trawl in mid-February were ready to spawn and also the fact that there is a 12.75-day hatch time for Pacific cod eggs at 7°C (Forrester, 1964). None of the gadoid larvae in the samples had yolk sacs and many were fairly well developed, suggesting that these larvae may have been the result of spawning which occurred 20 to 30 days before. The peak gadoid larvae abundance observed in late April might have been the product of Pacific cod spawning in late March. The low incidence of gadoid larvae at station 1 may be a distributional effect or a sampling artifact, since only surface samples were taken at this station.

No Pacific cod eggs were positively identified from the samples. Thompson (1963) observed that Pacific cod lay demersal eggs in Canadian waters. The Pacific cod eggs which were artificially spawned for the rearing experiments were observed to be demersal but did not adhere to each other.

The occasional catches of adult Pacific cod in the trynet catches during the study period substantiated the observations of Gosho (1976) that the populations disperse after spawning but still occupy the same general area. The small size of the trynet made it a poor sampling device for adult cod, and therefore these catches were of particular interest.

The trynet catches of June 14 provided valuable data concerning juvenile Pacific cod distributions in the study area. The catches indicated that a substantial nursery area for Pacific cod was located in the northern portion of Kilisut Harbor. The shallow inshore waters to the north and south of Walan Point might also be important as nursery

grounds. Since the survival of these juvenile stages is often a significant factor in determining the recruitment into a commercial fishery, these areas may be of vital importance to the Port Townsend Bay Pacific cod fisheries.

These observations together with the large catch of one-year-old pre-recruit Pacific cod during the trawl survey of February 15 provided substantial support for the argument that this population of Pacific cod spends much of its early life in the bay itself.

5. Recommendations

a. The location of the spawning ground for Pacific cod in Port Townsend Bay has not been determined. By tagging a number of ripe female cod with ultrasonic tags it may be possible to track them to the spawning grounds.

b. More detailed ichthyoplankton sampling is essential if the distribution and abundance of larval Pacific cod is to be documented. A comprehensive rearing program would be an essential aspect of any ichthyoplankton study; rearing of Pacific cod, tomcod, and walleye pollock eggs and larvae is the only means of solving the taxonomic problem. Some information about egg mortalities could also be obtained in a laboratory rearing study.

c. The trynet sampling has yielded valuable data. Any further research should include an intensive trynet sampling program in late spring and early summer to locate and quantify the nursery grounds of the Pacific cod.

d. An estimate of the size of the Port Townsend Pacific cod population and some information regarding distribution and movements of the fish within the bay would be most valuable in determining the reproductive potential of the stock and the accessibility of the fish to the commercial fisheries. Such information could be obtained by carrying out an extensive mark-recapture study in which tagged fish would be released from a chartered trawler and recovered from the commercial fishery.

e. More accurate estimates of the size and age structure and the fecundity of the Port Townsend Pacific cod populations would be possible if the commercial set net fishery were sampled.

f. Although the Fisheries Research Institute's Trident salmonid outmigration study did not detect any Pacific cod in the Walan Point area, it would be wise to continue to monitor their field sampling work.

6. Literature Cited

Alderdice, D.F., and C.R. Forrester. 1971. Effects of salinity, temperature, and dissolved oxygen on early development of the Pacific cod (Gadus macrocephalus). J. Fish. Res. Board Can. 28:883-902.

Allen, K.R. 1966. A method of fitting growth curves of the von Bertalanffy type to observed data. J. Fish. Res. Board Can. 23:163-179.

Alverson, D.L. 1960. A study of annual and seasonal bathymetric catch patterns for commercially important groundfishes of the Pacific northwest coast of North America. Pac. Mar. Fish. Comm. Bull. No. 4, 66 pp.

Cobb, J.N. 1927. Pacific cod fisheries. Rept. U.S. Comm. Fish. for 1926, Appendix VII.

Ford, E. 1933. An account of herring investigations carried out at Plymouth during the years from 1924 to 1933. J. Mar. Biol. Ass. U.K. N.S. 19:305-384.

Forrester, C.R. 1964. Laboratory observations on embryonic development and larvae of the Pacific cod (Gadus macrocephalus Tilesius). J. Fish. Res. Board Can. 21:9-16.

Forrester, C.R., and D.F. Alderdice. 1965. Effects of salinity and temperature on embryonic development of the Pacific cod (Gadus macrocephalus). J. Fish. Res. Board Can. 23:319-340.

Gosho, M. 1976. Results of tagging of Pacific cod (Gadus macrocephalus) in Washington waters. Wash. Dept. Fish. Tech. Rept. No. 19, 42 pp.

Gulland, J.A. 1969. Manual of methods for fish stock assessment. Part 1. Fish population analysis. FAO, Rome, 154 pp.

Harris, C.K., and A.C. Hartt. 1977. Assessment of pelagic and nearshore fish in three bays on the east and south coasts of Kodiak Island, Alaska. Univ. Washington, Coll. Fish., Fish. Res. Inst., Circ. FRI-UW-7719. 190 pp.

Hart, J.L. 1949. Food of the fish of the cod family. Fish. Res. Board Can., Pac. Progr. Rep. 79:35-36.

Hart, J.L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. 180, 740 pp.

Healey, M.C., and R.A.W. Nicol. 1975. Fecundity comparisons for various stocks of lake whitefish, Coregonus clupeaformis. J. Fish. Res. Board Can. 32:404-407.

Kennedy, W.A. 1970. Reading scales to age Pacific cod (Gadus macrocephalus) from Hecate Strait. J. Fish. Res. Board Can. 27:915-922.

Ketchen, K.S. 1961. Observations on the ecology of the Pacific cod (Gadus macrocephalus) in Canadian waters. J. Fish. Res. Board Can. 18:513-558.

Ketchen, K.S. 1964. Preliminary results of studies on growth and mortality of Pacific cod (Gadus macrocephalus) in Hecate Strait, British Columbia. J. Fish. Res. Board Can. 21:1051-1067.

Moiseev, P.A. 1953. Cod and flounders of Far Eastern seas. Izv. Tikhooean. Nauchnoissled. Inst. Morsk. Rybn. Khoz. Okeanogr. 40:287 pp. (Trans. Fish. Res. Board Can., Ser. 119, 596 pp.).

Mukhacheva, V.A., and O.A. Zviagina. 1960. Development of the Pacific cod Gadus morhua macrocephalus. Til. Akad. Nauk SSSR Tr. Inst. Okeanl. 31:145-165. (Trans. Fish. Res. Board Can., Nanaimo, B.C.).

Posgay, J.A., R. Marak, and R.C. Hennemuth. 1968. Development and tests of new zooplankton sampling methods. ICNAF Res. Doc. 68/85 No. 2085.

Somerton, D. 1977. GROWFIT, a program for fitting growth curves to size-age data. NORFISH Report, 7 pp., mimeo.

Suyehiro, Y. 1934. Studies on the digestive system and feeding habit of the important fishes of the North Pacific. I. The cods, Gadus macrocephalus and Theragra chalcogramma. Bull. Jap. Soc. Scient. Fish. 3:8-14.

Thompson, J.A. 1962. On the fecundity of Pacific cod (Gadus macrocephalus Tilesius) from Hecate Strait, British Columbia. J. Fish Res. Board Can. 19:497-500.

Thompson, J.A. 1963. On the demersal quality of the fertilized eggs of Pacific cod, Gadus macrocephalus Tilesius. J. Fish. Res. Board Can. 20:1087-1088.

Walford, L.A. 1946. A new graphic method of describing the growth of animals. Bull. Mar. Biol. Lab. Woods Hole 90:41-47.

Yamamoto, G., and C. Nishioka. 1952. The development and rearing of North Pacific cod (Gadus macrocephalus Tilesius). Japan Sea Reg. Fish. Res. Lab. Spe. Publ., 1952:301-308. (Trans. Fish. Res. Board Can., Ser. 402, 18 pp.).