FRI-UW-7813
August 1978

FISHERIES RESEARCH INSTITUTE
College of Fisheries
University of Washington
Seattle, Washington 98195

PACIFIC COD (*Gadus macrocephalus*) STUDIES IN PORT TOWNSEND BAY, WASHINGTON

by

Bruce S. Miller, William A. Karp, and Gary E. Walters

TWO-YEAR PROGRESS REPORT
December 1976 - June 1978
Contract No. N 68248-76-C-0006
UNITED STATES NAVY

Approved:

Submitted: August 31, 1978

Robert L. Burgner, Director

Abstract

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. Research trawl sampling carried out in January and February of 1977 and 1978 provided material for the determination of basic statistics, age structure, stomach contents, and fecundity. Sampling of commercial trawl and setnet catches in 1978 also contributed to the statistics obtained. Port Townsend Bay cod were found to be fast growing and early maturing, and to have relatively 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, and on six occasions during the same period in 1978. Gadid (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 gadid larvae to species. Attempts to rear Pacific cod eggs and larvae were of limited success but work in progress should facilitate the identification of cod larvae from samples. Our attempts did confirm the demersal nature of the eggs. Diving operations and a bottom grab survey failed to locate spawning adults or eggs. Ultrasonic tagging and tracking of ripe females provided information on short-term movements within the study area but spawning sites were not located. 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.

Juvenile gadids were collected during trynet sampling in May and June 1978 from within Kilisut Harbor and several locations in Port Townsend Bay.

Table of Contents

List of Tables

List of Figures

Acknowledgements

We are indebted to a great number of people for their help in this study.

The students of Dr. Miller's "Life History of Marine Fish" class worked particularly hard in the field and the laboratory. The research opportunity provided a learning experience for them and invaluable help to us.

The assistance of Tom Oswold, master of the R.V. COMMANDO, with his crew, Olaf Rockness and Herman Ashby, are gratefully acknowledged. Dave Strickland, master of the R.V. MALKA, spent long hours at the wheel during ichthyoplankton and trynet sampling.

We would like to give special thanks to the many commercial fishermen of Port Townsend who gave so freely of information, friendly interest, and live fish for use in tracking. Bruce Samuelson, Leo Cramer, Dick Harmes, Larry and Maryna Lawson, and Carl Tormalin were especially helpful. Jim Roberts and the crew at Guilford Packing Company provided free access to the commercial catches and helped in many ways.

Many people assisted during the COMMANDO trawl cruises; we wish to thank Colin Harris, Doug Eggers, Steve Borton, Craig Wingert, Judy Calvin, Paul Anderson, Sue Paskell, Chris Happel, Steve Nord, and Dave Gaudet.

Andy Palmer kept the tracking boat operating and helped with small-boat work. Meredith Mamanakis was a very able assistant in much of the field work and we also thank Tom Quinn for helping with trynet work. Jon Barkas assisted with the tedious task of plankton sorting, Scott Chitwood prepared many of the fecundity samples, and Dave Gaudet helped with the age determination work.

Ultrasonic tracking was a labor-intensive job which could not have been completed without the help of Nancy Steinfort, Larry Moulton, Marsha Landolt, Dick Kocan, Tom and Julie Bell, Lee and Sue Stayton, Mary Spawn, Allen Shimada, Sue Paskell, Ken Semmens, Wanda Goldsmith, and Scott Christensen.

We are also indebted to the National Marine Fisheries Service (NMFS) for the use of the tracking equipment. Gordon Esterberg, Bill High, and their staff were particularly helpful.

Larry Moulton deserves special thanks for his assistance in making the diving surveys.

The staff of the NMFS ichthyoplankton laboratory at Montlake have worked hard helping us to resolve the taxonomic problems in the larvae and juveniles; Jean Dunn, Ken Waldron, Beverly Vinter, and Anne Matarese all deserve thanks. Dave Misitano at the NMFS Mukilteo laboratory successfully reared the early larvae. Steve Borton and Janet Ilg at the Seattle Aquarium also did some rearing work.

Mark Pedersen and Jim Beame of the Washington Department of Fisheries provided valuable support throughout the study.

We are grateful to Abby Simpson for typing the manuscript.

This study was supported by United States Navy Contract No. 68248-76-C-0006.

1. Introduction

This two-year progress report summarizes the information obtained from December 1976 to June 1978. It is not necessary to refer back to the one-year progress report (Karp and Miller 1977) since all pertinent information from that report has been included in this report.

The Pacific cod (Gadus macrocephalus) is widely distributed in the North Pacific Ocean. Hart (1973) described its distribution as being from Santa Monica, California, north to Alaska, the Bering Sea, the Chukchi Sea, and west to Kamchatka, the Sea of Japan, and the Yellow Sea. In the Eastern Pacific, commercially exploitable quantities of G. macrocephalus do not occur south of Destruction Island, Washington (Ketchen 1961). Cobb (1916) considered that Cape Flattery, Washington, was the southernmost point of the distribution of the species.

There has been considerable debate regarding the integrity of the species. Schultz and Welander (1935) considered G. macrocephalus to be distinct from the Atlantic cod (Gadus morhua) on the basis of air bladder morphology, color of the peritoneum, length of the depressed first dorsal fin, fin coloration, and length of the barbel, but they were unable to find any differences based on counts of fin rays and vertebrae or from "numerous measurements involving various parts of the body". Svetovidov (1948), however, classified Pacific cod as Gadus morhua macrocephalus, a subspecies of the Atlantic cod. It is significant that neither of these arguments considered the fact that the Atlantic cod produces a non-adhesive semi-pelagic egg while the Pacific cod produces a demersal, slightly adhesive egg (Thompson 1963). Wilimovsky, et al. (1967), considered that G. macrocephalus was indeed a full species with evidence of substantial differences between North American and Japanese stocks.

There were also indications of separate stocks in the northern Bering Sea, the western Bering, Alaska, and southern British Columbia.

Commercial exploitation of Pacific cod has taken place for many years. As early as 1765 a Russian navigator had observed "cod, perch, pilchards, and smelts" around the Fox Islands (Alaska) and later explorers, including Captain Cook, recorded similar observations (Cobb 1916). It was not until the mid-nineteenth century, however, that the Alaskan Pacific cod fishery began to develop; by the mid-1860s a handline fishery was established and ex-vessel prices for dried cod were 12-1/2 to 15 cents a pound in San Francisco. The fleet first operated in the Gulf of Alaska and slowly moved into the Bering Sea. Over a period of time, handlining gave way to longlining and some trawling also occurred. Cobb (1927) described the use of experimental gillnets in the early twentieth century but these were not adopted.

The fishery in Washington State did not develop until much later. In 1935 (WDF 1975) total landings of Pacific cod for the state were only 23,000 kg, even though Smith (1936) stated that the species was "very important commercially in Georgia Strait, Hale Passage and Washington Harbor" and that commercial catches took place in the "extraterritorial waters of the Washington coast". A steady increase in Washington State landings of Pacific cod occurred until the late 1950s, when annual catches exceeded 5.4 million kilograms. In successive years landings have fluctuated between 1.4 and 5.0 million kilograms. But in spite of this variability, Pacific cod has been the second or third most important trawl-caught fish in Washington since 1966 (Gosho 1976). Since 1972, Pacific cod has been the most important trawl-caught fish in British Columbia (Fish. and Env. Can. 1978), where catches are considerably higher than in Washington.

Gosho (1976) reported that 28% of the Washington catch was taken from the Washington waters of Puget Sound and the Gulf of Georgia. This was equivalent to between 0.7 and 1.1 million kilograms per year from 1966 to 1973. The major portion of this catch was taken from the eastern Strait of Juan de Fuca.

Thus, the Pacific cod of Washington is of considerable economic importance, and it is therefore surprising that so little is known of its biology and ecology. The classic work of Moiseev (1953) described in some detail the distribution, biology, and ecology of Pacific cod in the Northwestern Pacific. Ketchen (1961, 1964) presented information on the biology of the species in Canadian waters. He determined growth and mortality rates for trawl-caught fish, described seasonal movements, and discussed the potential of the commercial fishery. Cobb (1927) and Alverson (1960) provided background on the Pacific cod fisheries of coastal North America.

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 and Japanese waters (Mukhacheva and Zviagina 1960; Yamamoto and Nishioka 1952).

The results of tagging experiments carried out in Washington waters between 1966 and 1973 were described by Gosho (1976). His data indicated that cod in Washington waters consisted of a number of small subpopulations which retained a high degree of isolation. A very small proportion of the fish recaptured had migrated out of the area of marking, indicating at least some exchange between stocks. Seasonal migrations were observed in some areas.

One of these small subpopulations resides for part of the year in the waters of Port Townsend Bay, Washington. Adult cod are found in the bay during their January to March spawning season; for the remainder of the year, however, this stock is distributed over a wider area and densities in the bay are very low.

A trawl fishery for Pacific cod has been carried out in Port Townsend Bay since the 1920s and a setnet fishery was established in February 1975. Commercial fishing takes 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.

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. In 1976, when the U.S. Navy published plans for the construction of an extensive munitions 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. Materials and Methods

2.1 Adult Fish Surveys

Trawl surveys were conducted from the 19.8-m University of Washington research vessel COMMANDO during January and February in 1977 and 1978.

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 the adult cod on the commercial fishing ground in Port Townsend Bay.

Commercial catch data were collected at the Guilford Packing Company dock at Port Townsend marina in late February and early March 1978. Setnet and trawl catches were sampled independently. Commercial trawl operations took place in the north-central part of Port Townsend Bay (Fig. 1); the gear used was comparable to that employed on the COMMANDO. The setnet fishery extended from Walan Point, Indian Island, northeast along the northern edge of Indian Island and Marrowstone Island. This operation utilized sinking gillnets with a minimum stretch mesh size of 13 cm and was located in 3-25 m of water.

2.1.1 Basic Measurements

Pacific cod sampled on board the COMMANDO were measured for total length and weighed on a spring balance to the nearest 50 g 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.

Commercial fish catches were sampled randomly. All fish sampled were measured for total length, and sex was identified for most individuals by applying slight pressure to the abdominal area, causing eggs or sperm to be extruded. Weights were recorded from a subsample of the fish selected to represent a range of sizes. Data obtained from an experimental gillnet operation by the National Marine Fisheries Service (NMFS) on 19 February 1978 were included in this analysis.

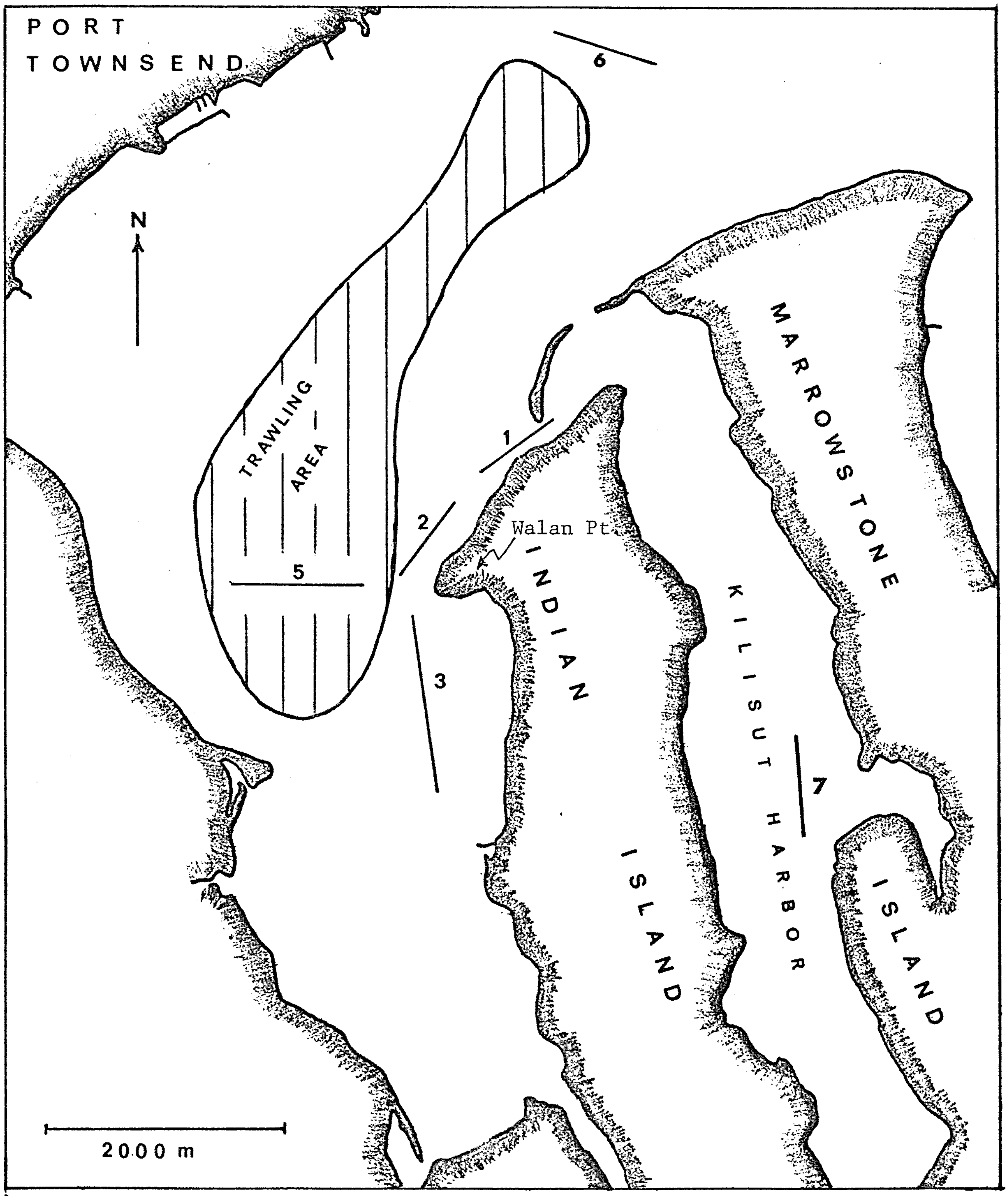

Fig. 1. Map of study area showing commercial trawl area and ichthyoplankton sampling transect stations 1-7.

2.1.2 Age and Growth

Length frequency histograms were prepared to allow comparisons between years, gear types, and sexes. Length frequency histograms for each age group were prepared from the age data obtained in 1977. Length-weight relationships were developed to describe growth characteristics. This was of the form,

$$W = aL^b$$

linearized to

$$\ell n\ (W) = \ell n\ (a) + b\ \ell n\ (L)$$

where W = weight in g,

L = total length in mm,

a and b are constants.

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 labeled envelope.

Scale samples were taken from a large proportion of the fish sampled by the COMMANDO. Similar samples were taken from larger fish encountered in the commercial catches in order to improve the size range of fish for age determination. 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 = ∞,

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.

Ageing of 1977 fish has been completed. The 1978 material is presently being analyzed.

2.1.3 Stomach Content Analysis

Stomach contents were examined from a subsample of the fish obtained during the COMMANDO surveys. Stomachs were first tied off at the esophagus, then cut above the tie and below the pyloric sphincter, 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 excess water had been blotted with a paper towel. The contents of each stomach were removed and the empty stomach was weighed 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 COMMANDO 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, 2,000, or 5,000 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 exponential model of the form,

$$F = aL^b$$

which linearizes 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 Juvenile Fish Surveys

Two nets were utilized in the juvenile fish surveys. A small trynet was used exclusively in 1977 and during February, March, and May 1978. This miniature otter trawl had a 4.7-m headrope, 6-m overall length, and was towed by a single cable attached to a 6.8-m bridle. The body mesh was 3.8-cm stretch mesh and the cod end 2.9-cm stretch mesh, but the cod end was lined with 0.64-cm stretch mesh. During April and June 1978, a larger trynet was used. This net had a 7.5-m headrope and was 10.8 m in total length. It was towed by an 18.6-m bridle. Mesh sizes were identical to those of the small net.

Most of the trynet sampling was carried out during the ichthyoplankton sampling cruises to provide supplementary data. Hauls were made in both deep (18-27 m) and shallow (4-18 m) water (Fig. 2) from February to June in 1977 and 1978. On 26 and 27 June 1978, the most extensive survey was made within Kilisut Harbor and at several stations in Port Townsend Bay.

Hauls varied between 5 and 30 min in duration; temperature profiles were taken periodically with a Beckman S-T probe. Species of fish were identified and gadids (fishes of the cod family) were enumerated from each catch. When small catches of gadid juveniles were made, all fish were

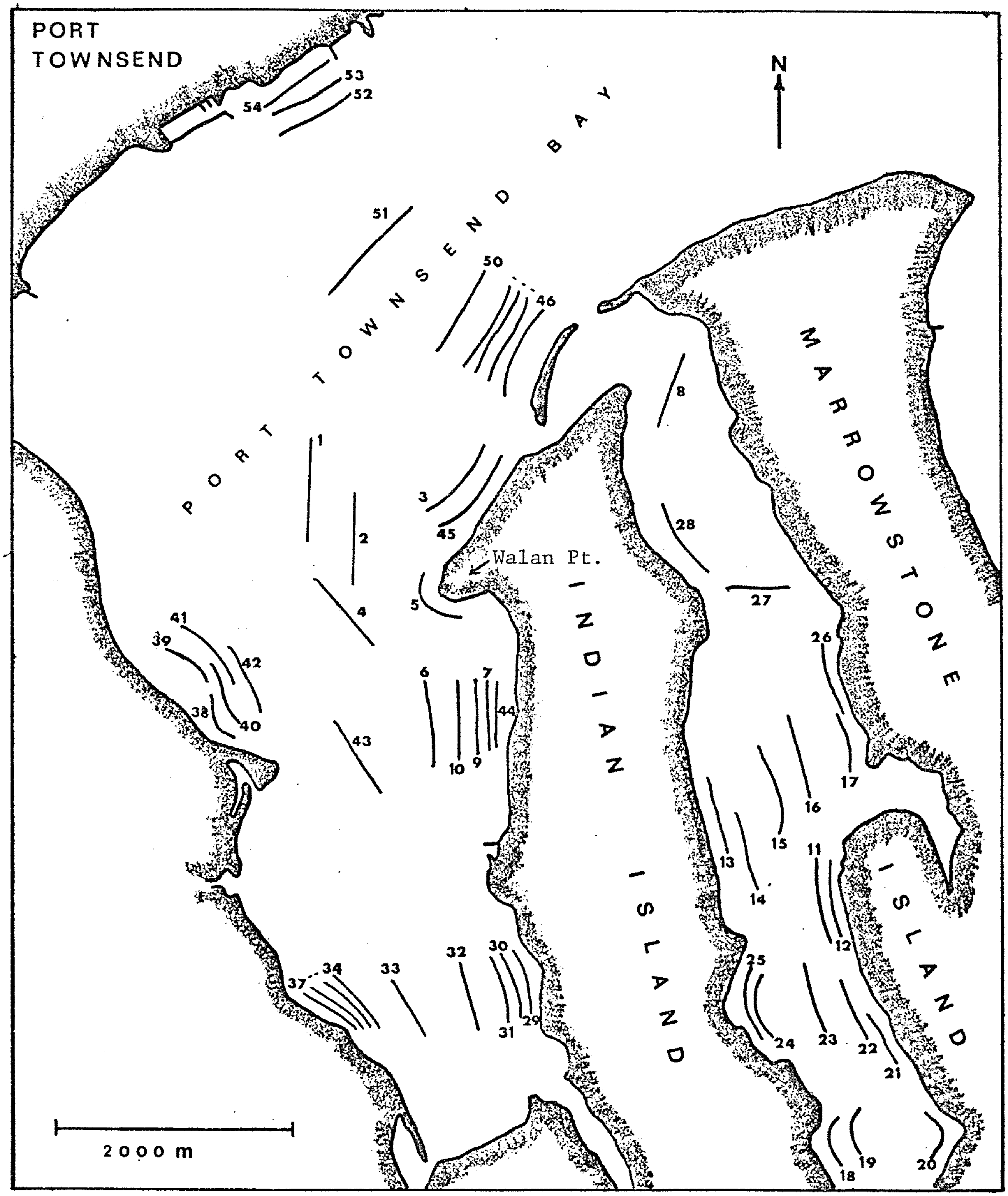

Fig. 2. Map of study area showing all trynet sampling locations. Stations 1-8 were sampled in 1977; stations 3 and 6-54 were sampled in 1978.

measured, weighed, and tentatively identified. When large catches occurred, a total count was taken and a subsample selected for analysis. This work is still proceeding.

2.3 Egg and Larval Surveys

Ichthyoplankton surveys were carried out from the 10.7-m University of Washington research vessel MALKA. A 60-cm aluminum bongo net array (Posgay, et al., 1968) was used for sampling. Nitex nets of 0.505-mm mesh were used for all tows. Seven sampling transect stations were established (Fig. 1, p.6). Stations 1-5 were sampled in 1977 and 1978, although stations 3 and 4 were combined later in 1977. Transect stations 6 and 7 were added in 1978.

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

Ichthyoplankton sampling was carried out on six occasions in 1978 from 12 February to 2 June. Based on the results of the 1977 study, gadid larvae were not expected to be encountered during the February trip. Therefore, on this occasion replicated tows were made only at station 1 for statistical evaluation of the sampling procedure. Stations 1, 2, and 6 were sampled on all subsequent trips. Stations 3 and 5 were sampled on all occasions except 1 June. Station 7 was sampled on 28 March, 3 May, and 1 June. Station 6 was added to the 1977 sites because of evidence gathered during ultrasonic tracking, and station 7 was added to examine Kilisut Harbor in greater detail. All ichthyoplankton sampling was carried out after dark. Station 1 was in relatively shallow water and the nets were towed at a fixed depth just below the surface. All other stations were sampled with oblique tows.

Surface sampling was carried out by bringing the vessel onto station, setting the engine speed to 600 rpm, and lowering the gear just below the surface. All surface tows were 5 min in duration. Oblique sampling was carried out by lowering the gear as quickly as possible while moving forward at 600 rpm; between 30 and 45 m of cable was released, depending on bottom depth. The gear was then winched slowly to the surface while the vessel maintained constant speed. Towing duration for oblique tows varied from 3 to 15 min.

At the completion of each haul, the gear was suspended above the surface and carefully hosed down to concentrate organisms in the cod end buckets and prevent contamination of subsequent hauls. All plankton was stored in glass jars and preserved with 5% buffered formalin. General Oceanics flowmeters were used to determine the volume of water filtered by each net haul. Flowmeter readings were recorded before and after each haul. Bathykymograph traces were obtained to determine the path of the gear during the oblique tows.

In the laboratory, samples were sorted under an illuminated magnifier or binocular microscope. 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 binocular microscope for counting and identification to the family Gadidae. Concentrations of eggs and larvae per 100 cubic meters of water were calculated using the flowmeter data.

2.4 Ultrasonic Tagging and Tracking

Ultrasonic tagging of Pacific cod had not been previously performed, although Atlantic cod have been tagged with ultrasonic devices for tracking (Hawkins, et al., 1974; Dalen 1974). Our ultrasonic tagging and tracking of ripe female Pacific cod was carried out as part of an attempt to locate spawning areas.

Ultrasonic tagging was conducted during the period 19 February to 8 March 1978. Preliminary tests were performed in January and early February by inserting the transmitters into fish captured during the trawl surveys and holding the fish in large tanks on deck for observation periods of up to 48 hours.

Ripe and running female cod to be used for tracking were obtained from commercial setnets and experimental gillnets of the National Marine Fisheries Service. For each tracking experiment several fish which appeared healthy and active were brought aboard and placed in a 120-liter plastic container with fresh seawater. The most active fish was selected and a 75-kHz transmitter (Smith-Root Inc. SR-69A) was inserted through the esophagus into the stomach. The fish was held for approximately ten minutes before release. Some fish were tagged externally with a small dart tag for additional identification.

Tracking was performed from a University of Washington 8-m open boat using a Smith-Root Inc. Type TA receiver and a directional transducer manufactured by the National Marine Fisheries Service. The tracking procedure was to rotate the submerged hydrophone transducer until maximum signal strength occurred. The boat was then moved in the direction indicated by the hydrophone until it was possible to obtain maximum signal strength at any position of the hydrophone. The boat was then considered to be above the fish. The time was noted and the position of the boat was determined by taking a series of horizontal angles between three fixed points on land with a sextant. The calculations for positional plotting were later performed by the University of Washington CDC 6400 computer system using a program written by one of the authors (G.E. Walters).

2.5 Diving Operations

A series of eight SCUBA dives was made in the study area during the 1977 season. Six of these dives were utilized to survey the dock construction area. These dives were carried out on 16 January, 5 February, 25 February, 5 March (two dives), and 18 March (at night). Two dives were made in the entrance to Kilisut Harbor, close to ichthyoplankton station 1 (Fig. 1).

Five of the 1977 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 (25 February) at the Kilisut Harbor entrance covered the approximate area indicated by station 1 (Fig. 1). The other dive (5 March), in the same general area, consisted of swimming slowly along a commercial setnet near the shoreline of Indian Island.

Three SCUBA dives were conducted in 1978. On 1 March, diving was conducted near the northwest end of Marrowstone Island; on 9 March observations were made over the Mid-Channel Bank near ichthyoplankton station 6. These dives were conducted in areas which appeared to be possible spawning grounds based on the results of the tracking studies. An additional dive was made in Agate Pass (Bainbridge Island) on 22 March over an area assumed to be a spawning ground of the Pacific cod.

2.6 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 1977. Two transects were sampled at 2-m or 4-m depth increments. Eleven samples were taken and examined for the presence of fish eggs and for substrate characteristics.

2.7 Early Life History Studies

Laboratory rearing experiments were attempted on two occasions in 1977. 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.

Three batches of fertilized eggs were transported to the NMFS Mukilteo laboratory during the 1978 season. On two occasions larvae were hatched from the eggs.

3. Results

3.1 Adult Fish Surveys

3.1.1 Basic Measurements

A total of 569 Pacific cod was caught during the R.V. COMMANDO trawl surveys in January and February 1977 (Table 1). The catch-per-unit-of-effort (CPUE) was greater both in biomass and numbers in February than in January. 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

Table 1. Research trawl catches of Pacific cod in Port Townsend Bay, 1977 and 1978.
Note: Sex was not determined for all fish in 1977.

Date	No. of hauls	Duration (min)	Male n	Male $\overline{L}$ (mm)	Male $\overline{W}$ (g)	Female n	Female $\overline{L}$ (mm)	Female $\overline{W}$ (g)	All fish n	All fish $\overline{L}$ (mm)	All fish $\overline{W}$ (g)	Total weight (kg)	CPUE kg/hr
Jan. 77	5	250	73	423	940	84	470	970	157	451	960	157.6	37.8
Feb. 77	3	120	205	451	980	168	464	1080	373	457	1030	385.7	192.9
Total 77	8	370	278	448	970	252	462	1040	530	455	1010	543.3	88.1
Jan. 78	5	225	7	449	1250	23	451	1130	30	451	1190	35.8	9.5
Feb. 78	7	370	128	442	1030	144	469	1280	272	457	1160	315.6	51.2
Total 78	12	595	135	443	1040	167	466	1270	302	455	1160	351.1	35.4

in the February catches. The average length of females was greater than the average length of males in all catches, except haul 2 of 15 February which was the only nighttime sample. 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 was observed in the February catches.

In January and February 1978, 302 Pacific cod were caught during the COMMANDO trawl surveys in Port Townsend Bay (Table 1). The CPUE both in biomass and in numbers was considerably greater in February than in January. In 1978 there were fewer males in both January (7:23) and February (128:144). Mean length and weight were similar for males and females. All the fish sampled in January were approaching spawning maturity, whereas in February most fish were clearly mature or ripe.

From the commercial catch in Port Townsend Bay, 615 Pacific cod were sampled in 1978 (Table 2). The trawl sample consisted of more males than females (155:84). Females were larger with an average length of 490 mm and an average weight of 1,700 g. Males averaged 439 mm in length and 1,000 g in weight. The sample taken from the setnet fishery consisted of fewer males than females (151:199). Females were larger than males and had an average length of 544 mm and an average weight of 2,050 g. The males averaged 532 mm in length and 1,750 g in weight.

3.1.2 Age and Growth

Length frequency histograms were prepared for all the fish caught by trawl from the COMMANDO for 1977 and 1978 (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

Table 2. Commercial and combined commercial and research sample summaries for adult Pacific cod in Port Townsend Bay, 1978.

Source	Length data (mm)				Weight data (g)			
	n	$\bar{L}$	Lmin	Lmax	n	$\bar{W}$	Wmin	Wmax
Commercial trawl 1978 males	155	439	355	650	124	1000	550	3300
Commercial trawl 1978 females	84	490	390	670	65	1700	800	4100
Commercial trawl 1978 combined[a]	256	456	355	670	204	1200	500	4100
Commercial set net 1978 males	151	532	375	675	101	1750	700	3800
Commercial set net 1978 females	199	544	405	750	111	2050	700	5600
Commercial set net 1978 combined[b]	359	540	375	750	213	1900	700	5600
Commercial and research 1978 males	441	472	255	675	360	1250	150	3800
Commercial and research 1978 females	450	505	245	750	343	1600	100	5600
Commercial and research 1978 combined	917	489	245	750	719	1400	100	5600

[a] Sex not determined in 17 cases.

[b] Sex not determined in 14 cases.

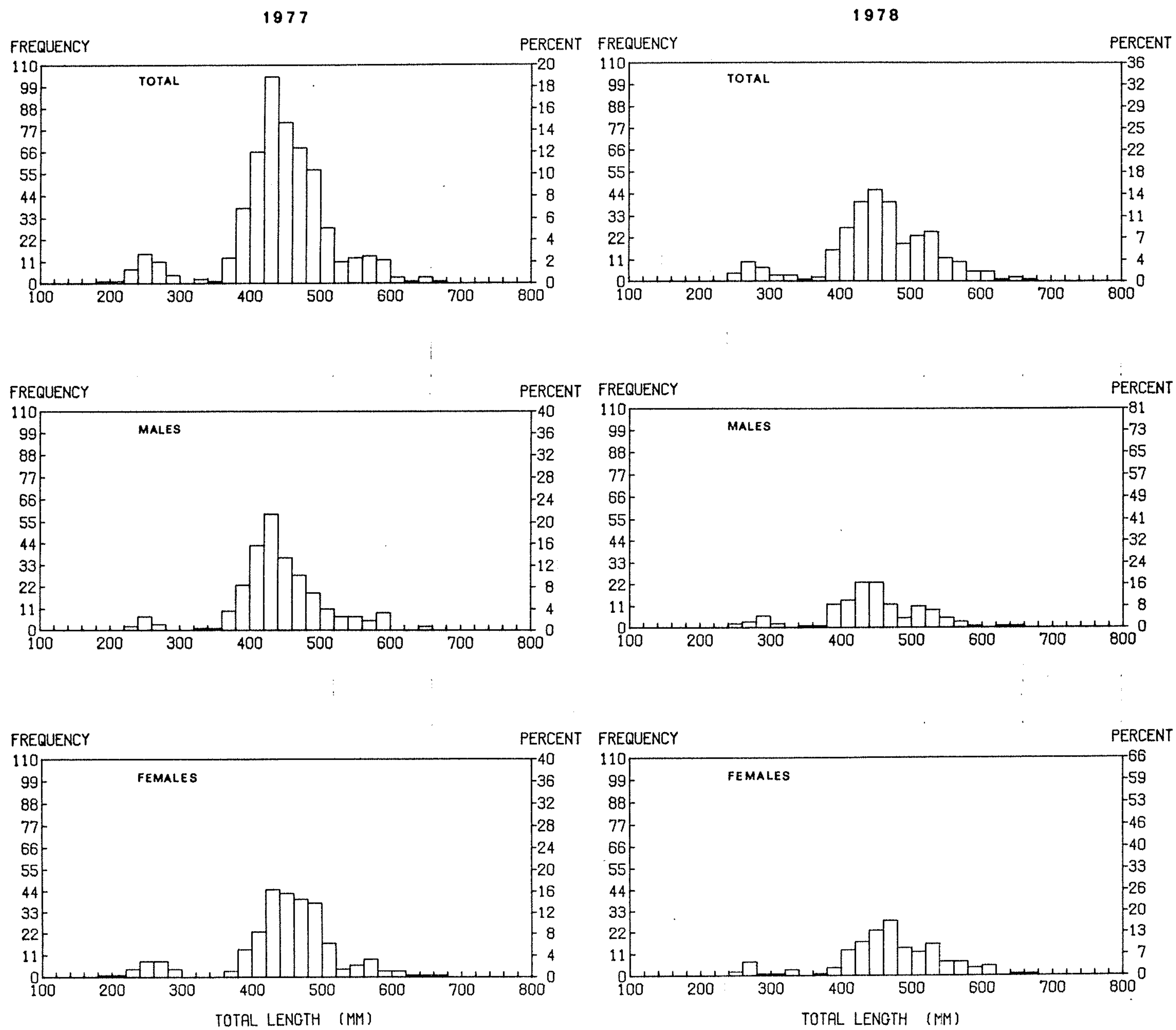

Fig. 3. Length frequency histograms for 1977-1978 research trawl catches (R.V. COMMANDO).

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.

Length frequency histograms were prepared for all Pacific cod samples obtained in 1978 (Fig. 4) and for each sex and gear type (Figs. 5 and 6). Research and commercial trawl catches were combined, but it should be noted that commercial trawler crews discard almost all fish smaller than about 350 mm in length, and thus the smaller length groups are incompletely represented by the histograms.

Length-weight relationships were calculated for COMMANDO-caught fish by year and sex (Table 3). Appropriate weights at length were computed from these relationships for comparison. All the relationships obtained were similar. The range of values of the exponent (b) was 3.061 to 3.348. The highest value was for female COMMANDO-caught fish in 1978. Weight at a given length was generally greater for females, particularly at lengths of 400 mm of greater. Maturity stages were not considered in developing these relationships. Since the coefficients obtained were quite similar, it was considered appropriate to combine 1977 and 1978 data and compute length-weight relationships for all fish and each sex (Table 3, Fig. 7).

Age was determined for 272 of the fish sampled in 1977. Body-length: scale-width relationships were determined independently for males, females, and all fish (Table 4). Relationships were similar in all cases. The "all fish" category included a small sample of large unsexed fish from the commercial setnet fishery. Age group characteristics for the aged fish were also calculated (Table 5).

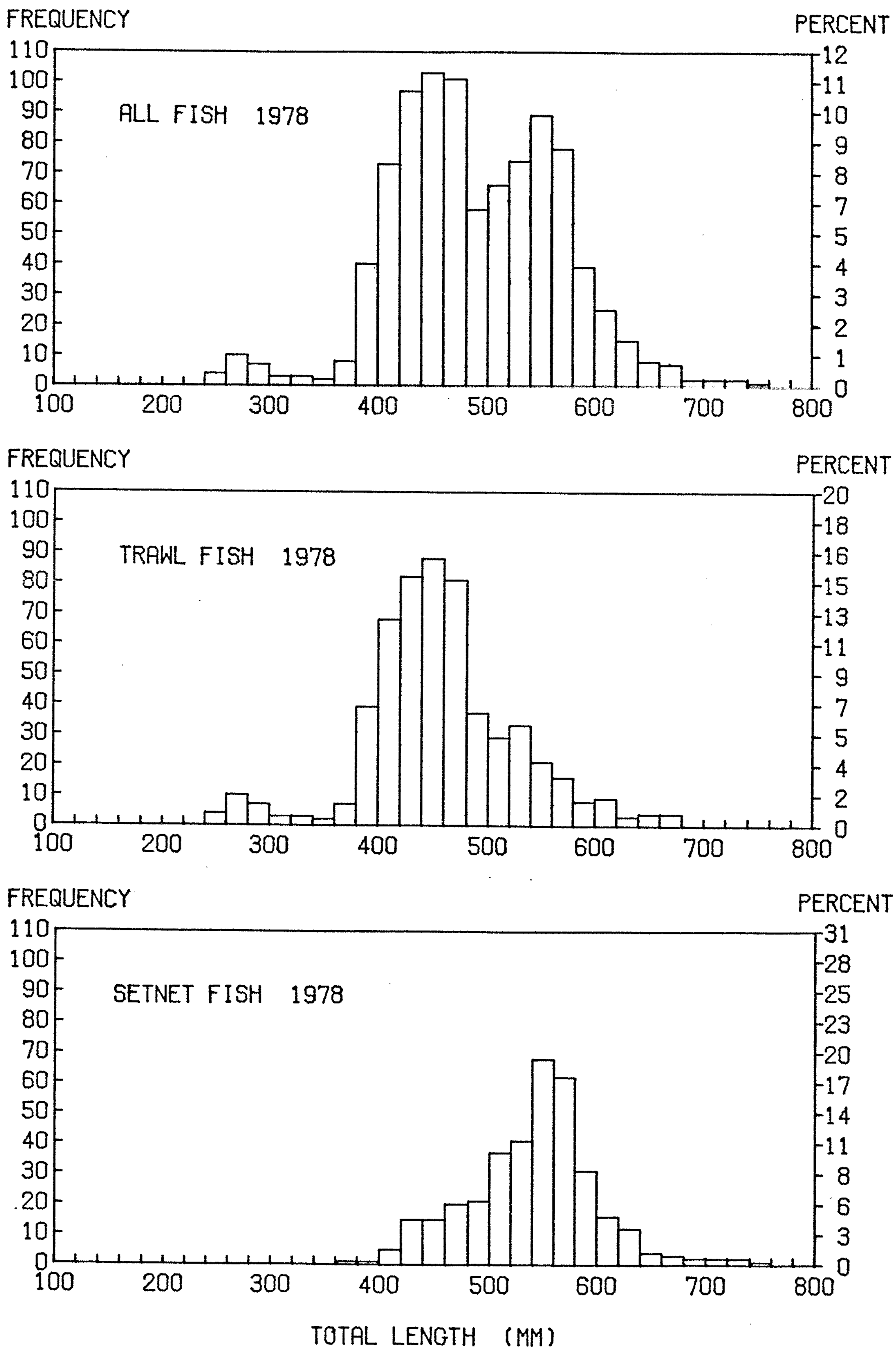

Fig. 4. Length-frequency histograms for all 1978 samples.

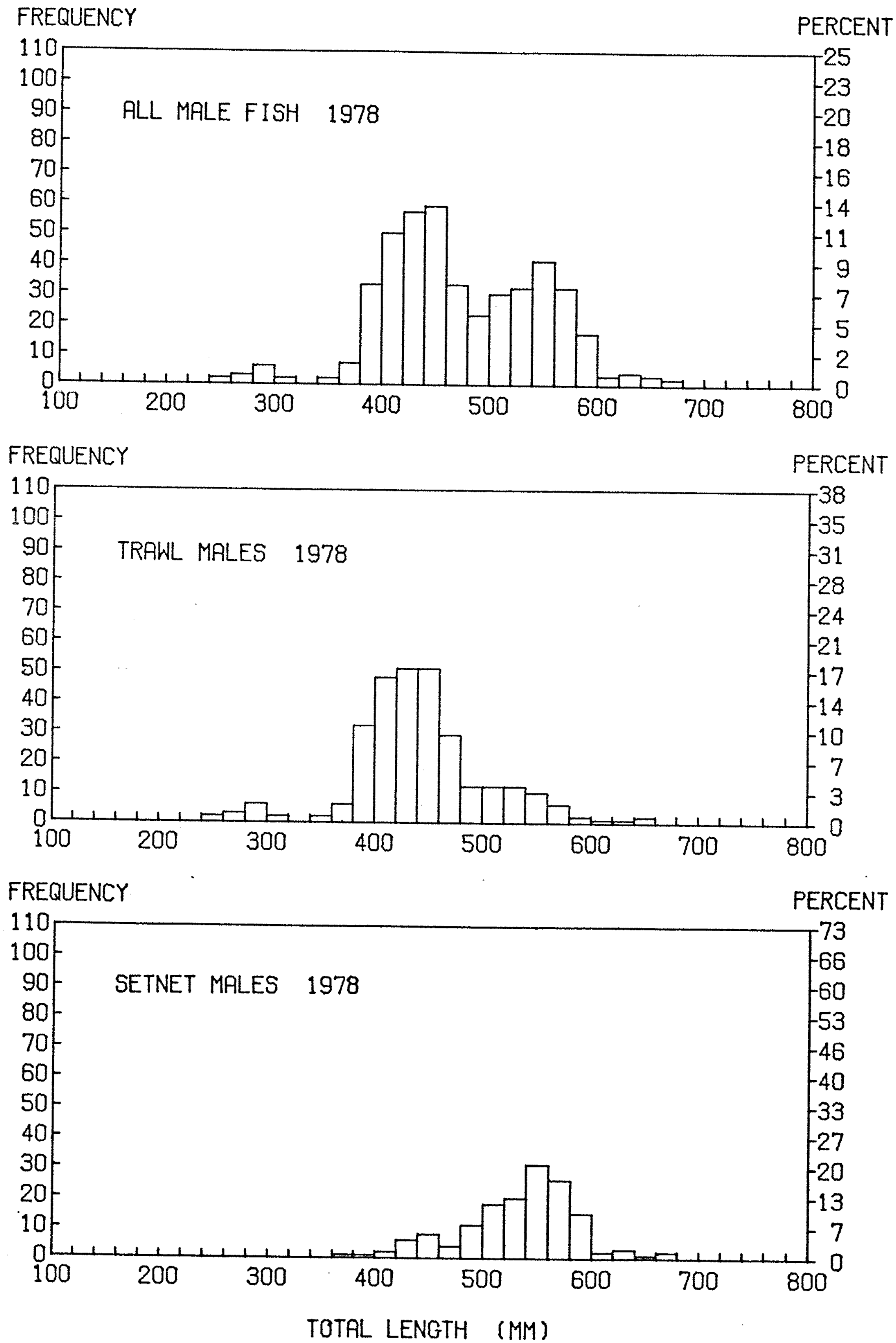

Fig. 5. Length-frequency histograms for all 1978 males.

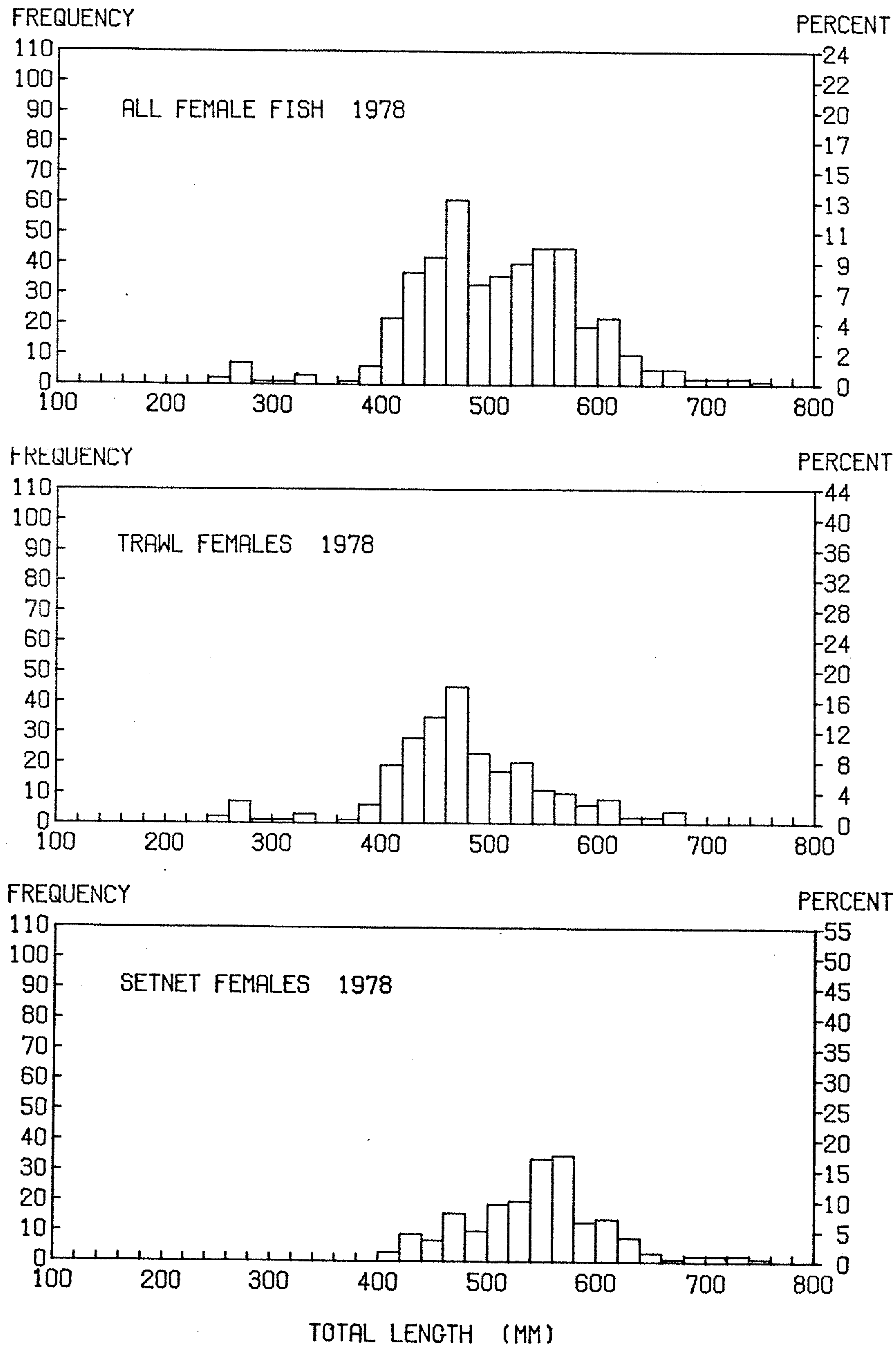

Fig. 6. Length-frequency histograms for all 1978 females.

Table 3. Length-weight relationships for 1977 and 1978 with estimates of weight (g) for given lengths. Note: Sex was not determined for all fish in 1977.

Source	Coefficients from $W = aL^b$		Lengths (mm)						n
	a	b	200	300	400	500	600	700	
1977 COMMANDO males	$4.143x10^{-6}$	3.145	71	255	631	1273	2258	3667	274
1977 COMMANDO females	$6.032x10^{-6}$	3.086	76	266	647	1288	2260	3637	275
1977 COMMANDO all fish	$5.382x10^{-6}$	3.103	74	262	640	1279	2252	3634	553
1978 COMMANDO males	$7.556x10^{-6}$	3.061	83	289	697	1379	2410	3862	135
1978 COMMANDO females	$1.328x10^{-6}$	3.348	67	261	684	1443	2657	4452	167
1978 COMMANDO all fish	$2.764x10^{-6}$	3.228	74	273	692	1421	2560	4211	302
1977 + 1978 COMMANDO males	$5.203x10^{-6}$	3.112	75	266	652	1306	2304	3722	409
1977 + 1978 COMMANDO females	$3.054x10^{-6}$	3.203	72	263	661	1351	2423	3971	442
1977 + 1978 COMMANDO all fish	$3.826x10^{-6}$	3.165	73	264	657	1352	2372	3863	855
1977 + 1978 total males	$5.157x10^{-6}$	3.118	77	274	671	1345	2376	3842	633
1977 + 1978 total females	$2.252x10^{-6}$	3.258	71	265	675	1397	2531	4181	618
1977 + 1978 total all fish	$3.171x10^{-6}$	3.200	73	268	672	1372	2459	4027	1271

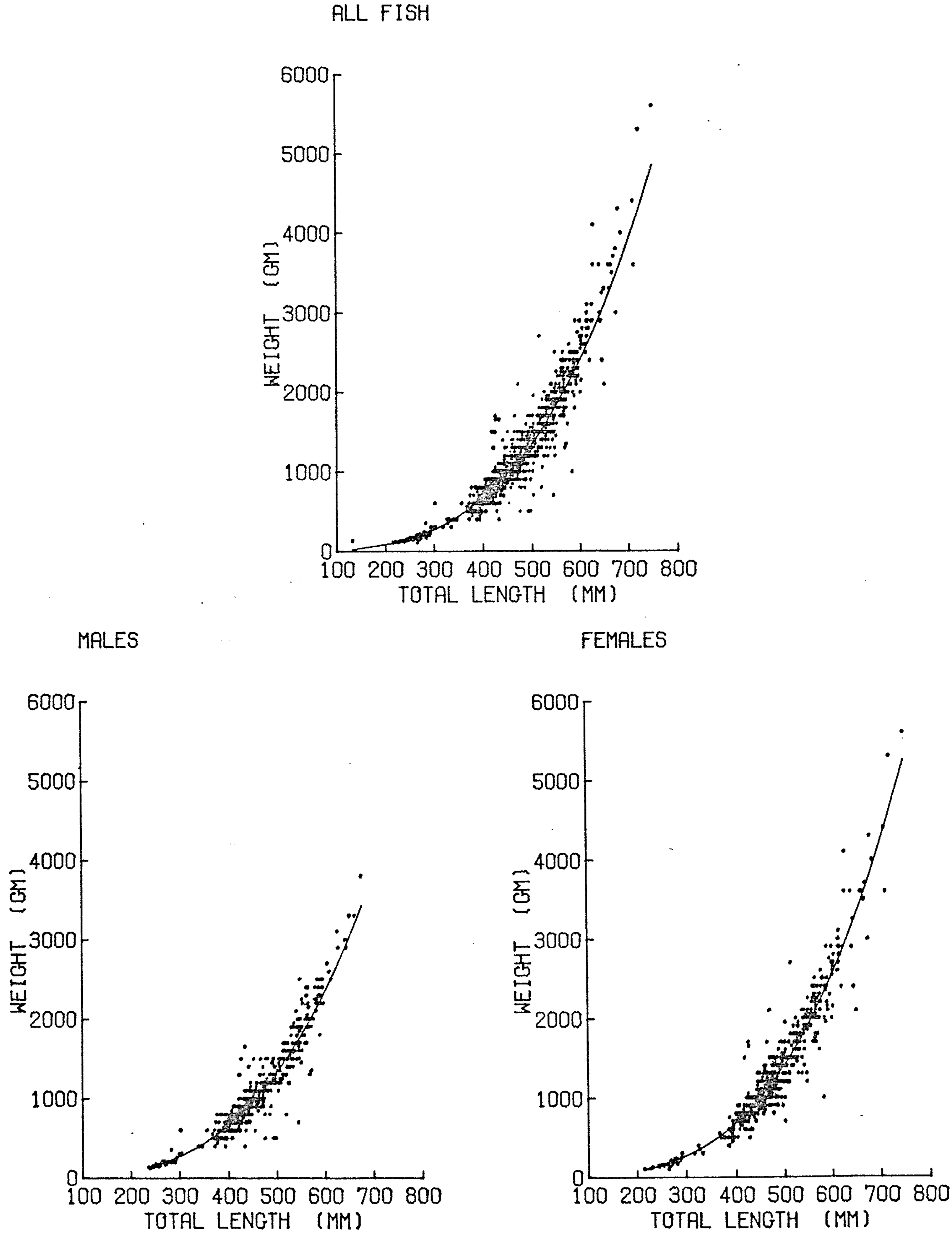

Fig. 7. Length-weight relationships for all 1977-78 Pacific cod samples.

Table 4. Body-length : scale-width relationships of the form length = a (scale width)^b for 1977 data.

	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 setnet fish.

Table 5. Age group characteristics for 1977 data.

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 setnet fish.

An examination of the length frequency by age data (Fig. 8, Table 5) demonstrated that most of the fish examined were two or three years old. While all one-year-old fish were clearly segregated by size from the other age groups, there was much overlap in size between two- and three-year-old fish. However, no females were caught that were older than three years. One trawl-caught male was four years old. The setnet 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 6). 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 setnet fish (Fig. 9):

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

A sample of 297 scales collected from research and commercial catches in 1978 is presently being analyzed.

3.1.3 Stomach Content Analysis

Stomach contents for 106 fish sampled in January 1977 and 213 fish sampled in February 1978 were analyzed and evaluated for percentage of occurrence of crustaceans, fish, and empty stomachs. Preliminary examination of the data indicated no significant differences between sexes or between sizes of fish, and therefore, a breakdown of the observations by time of day was prepared (Fig. 10).

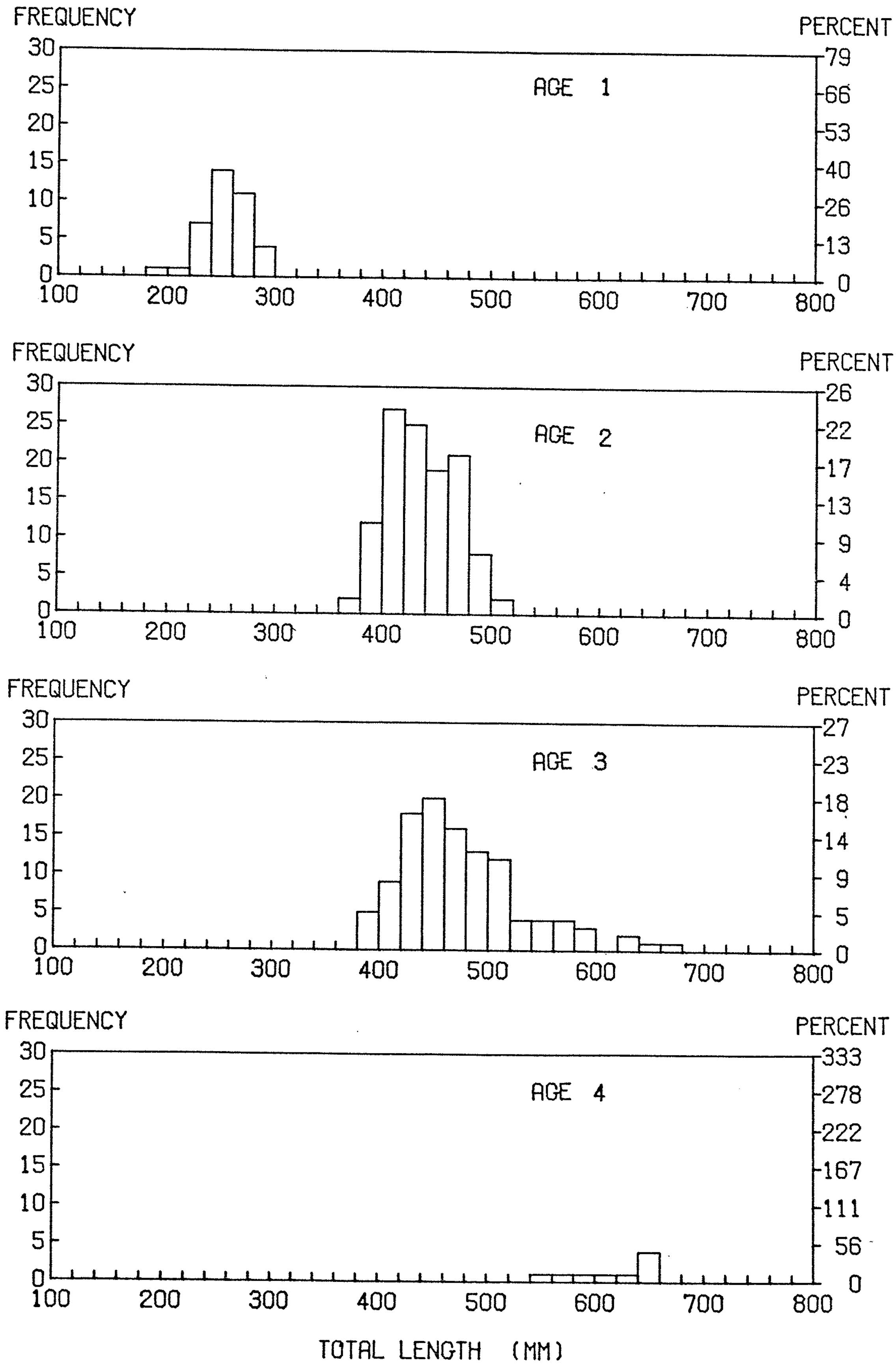

Fig. 8. Length-frequency histograms by age for 1977 samples.

Table 6. Von Bertalanffy growth curve parameters for 1977 data.

	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 setnet fish.

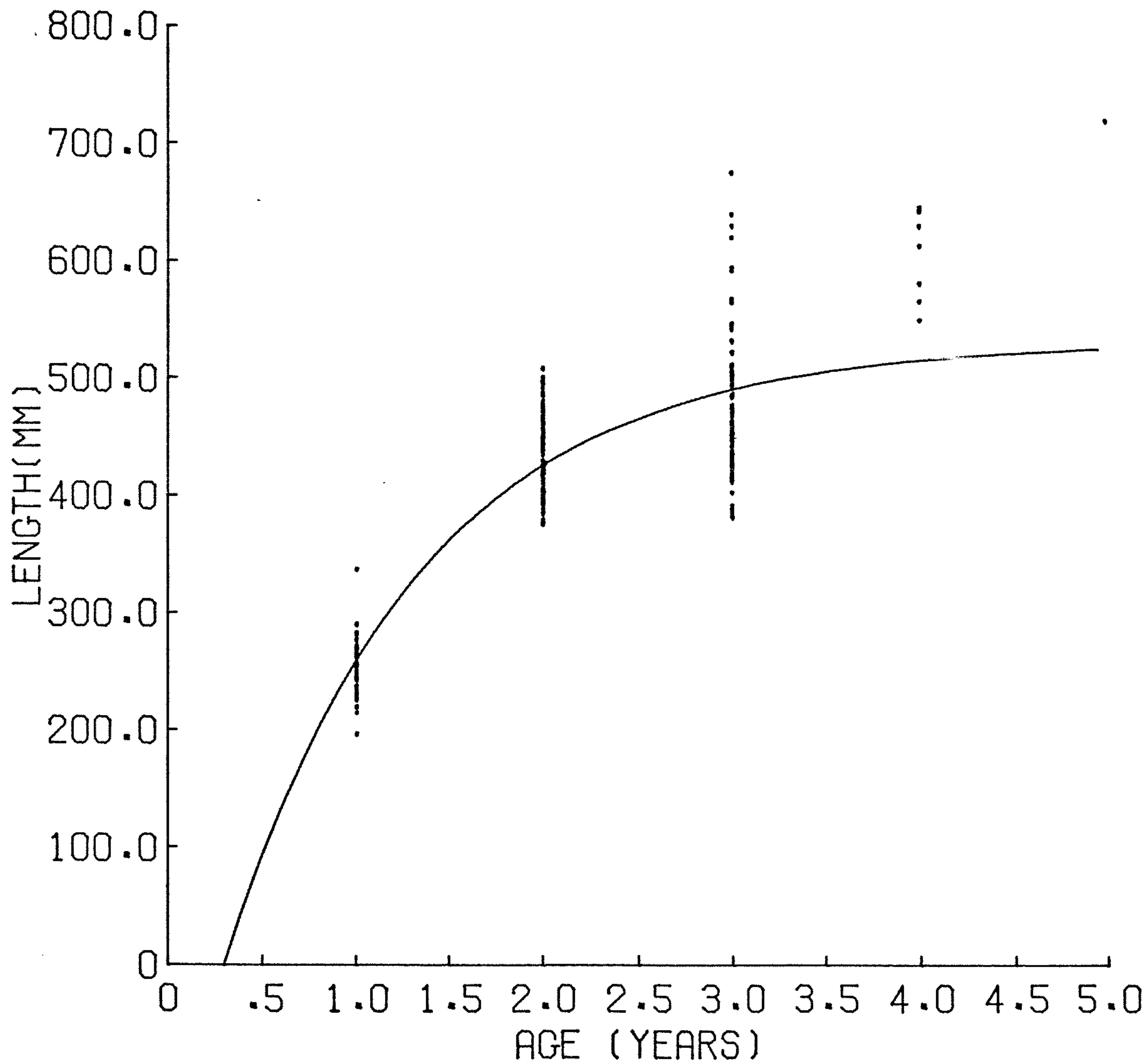

Fig. 9. Von Bertalanffy growth curve for trawl and setnet catches in 1977.

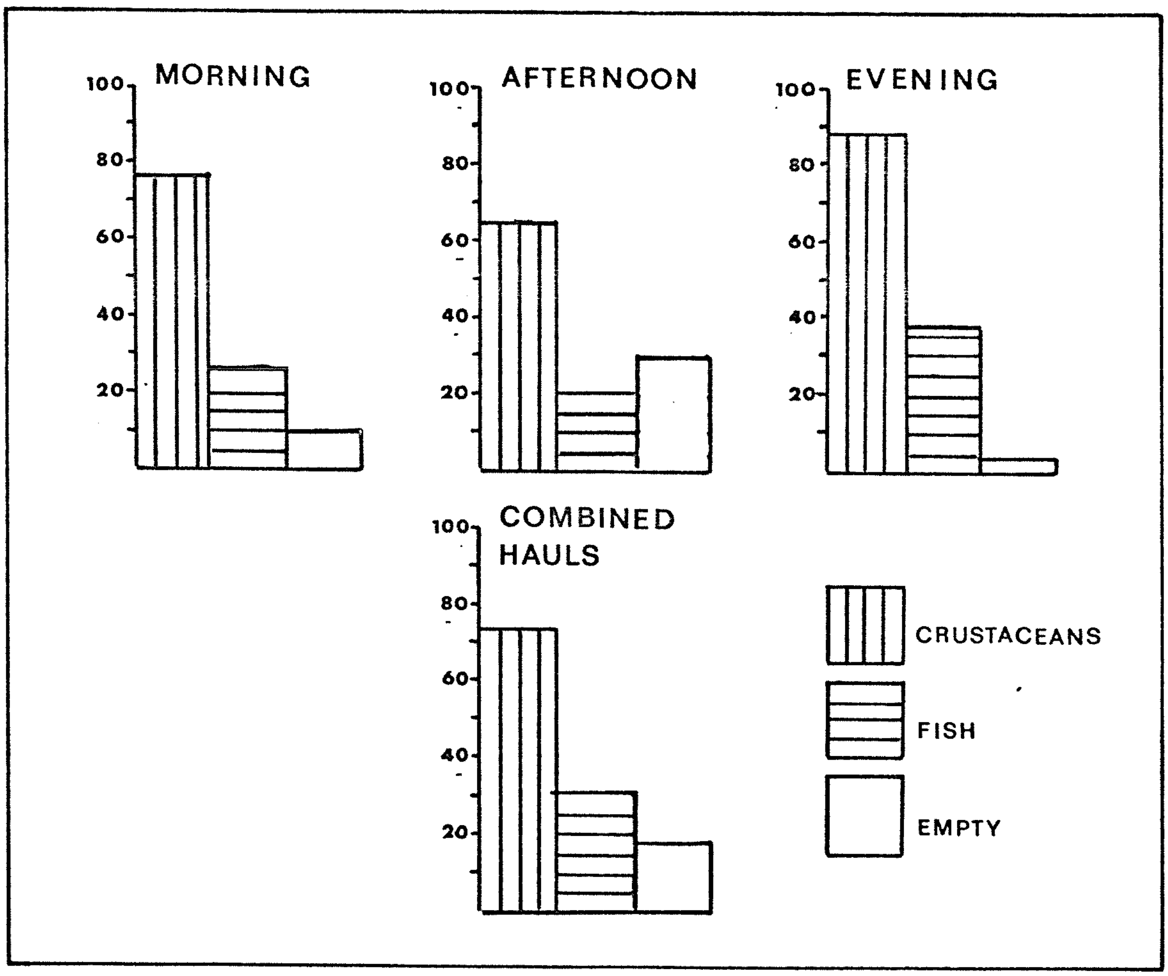

Fig. 10. Frequency of occurrence of major food categories by time of day.

Crustaceans appeared to be the preferred food item. This category was composed largely of shrimp, although mysids were also important. Fish (juvenile herring, small cottids) are also very important food items of Pacific cod, particularly in terms of biomass. The incidence of empty stomachs was greatest in the afternoon, indicating the possibility of increased feeding activity at dawn and dusk.

3.1.4 Fecundity Information

Ovaries from 40 fish sampled in 1977 and 3 fish sampled in 1978 were utilized for fecundity estimation. The relationship computed was

$$\text{Fecundity} = (1.3217 \times 10^{2})(\text{Total Length}^{2.9589})$$

where $R^2 = 0.653$ (Fig. 11). Calculated estimates of fecundity for females of 400, 500, and 600 mm total length were 661,000; 1,280,000; and 2,195,000 eggs per female, respectively. The three samples added in 1978 reduced the fecundity estimate for larger fish and slightly increased the estimate for smaller fish.

3.2 Juvenile Fish Surveys

Eight trynet station-transects were sampled during 1977 (Fig. 2, p. 11), although not all stations were sampled on each sampling trip (Table 7). No juvenile gadids were caught until 14 June when samples were obtained at all stations sampled. Juvenile Pacific cod were positively identified from the samples taken at stations 3, 7, and 8 (Fig. 12). Particularly noteworthy was the large catch of juvenile Pacific cod at station 8 in Kilisut Harbor. These juvenile cod ranged in size from 30 to 93 mm total length, the greatest frequency being between about 40 and 50 mm total length. Since all juveniles were caught in June, they were estimated to be about two to three months old.

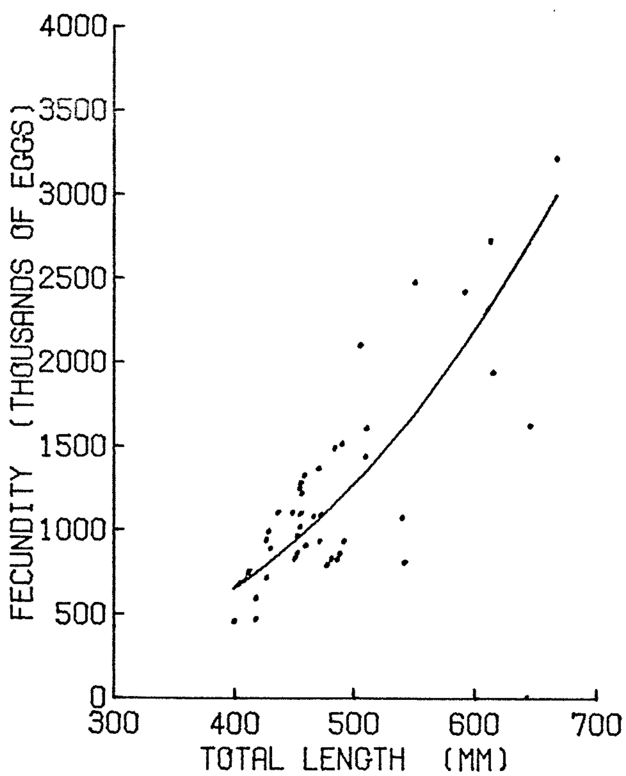

Fig. 11. Length-fecundity relationship.

Table 7. Trynet catches of juvenile gadoids for 1977 and 1978.

Station No.:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Depth (m):	22	27	18	27	27	27	9	7	11	16	8	5	3	5	8	11	5	3	5	3	3	5	6	5	3	3	8	7
Date																												
15 Apr 1977§				0																								
29 Apr 1977§			0		0	0																						
23 May 1977§		0				0	0																					
14 Jun 1977§	0	0	1			0	5	74																				
12 Feb 1978						0*		0			0			0	0*	0	0				0		0		0	0	0	0
6 Mar 1978			0			0		0*				0*				0*	0*											
28 Mar 1978			0			0*		0				0				0	0											
13 Apr 1978								0*				0				0	0											
3 May 1978			0			0	0	0*	0	9		1*	0	4	19	26*	0											
1 Jun 1978			1			36	0	0	17	11	46	0	0	0	130	846												
26 Jun 1978								3					0	0	408	306	42	0	18	0	0	0	31	1	29	0	11	
27 Jun 1978						143	0		1	171																		

Station No.:	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Depth (m):	4	5	11	16	21	16	11	5	3	3	5	11	16	22	26	3	3	3	5	11	16	22	16	11	5	3
Date																										
27 Jun 1978	1	0	0	28	18	132	41	3	0	1	16	41	208	96	62	0	1	18	27	162	89	55	7	0	0	0

*Replicate hauls made; catch is total of both hauls.
§Data for 1977 are for catches of Pacific cod.

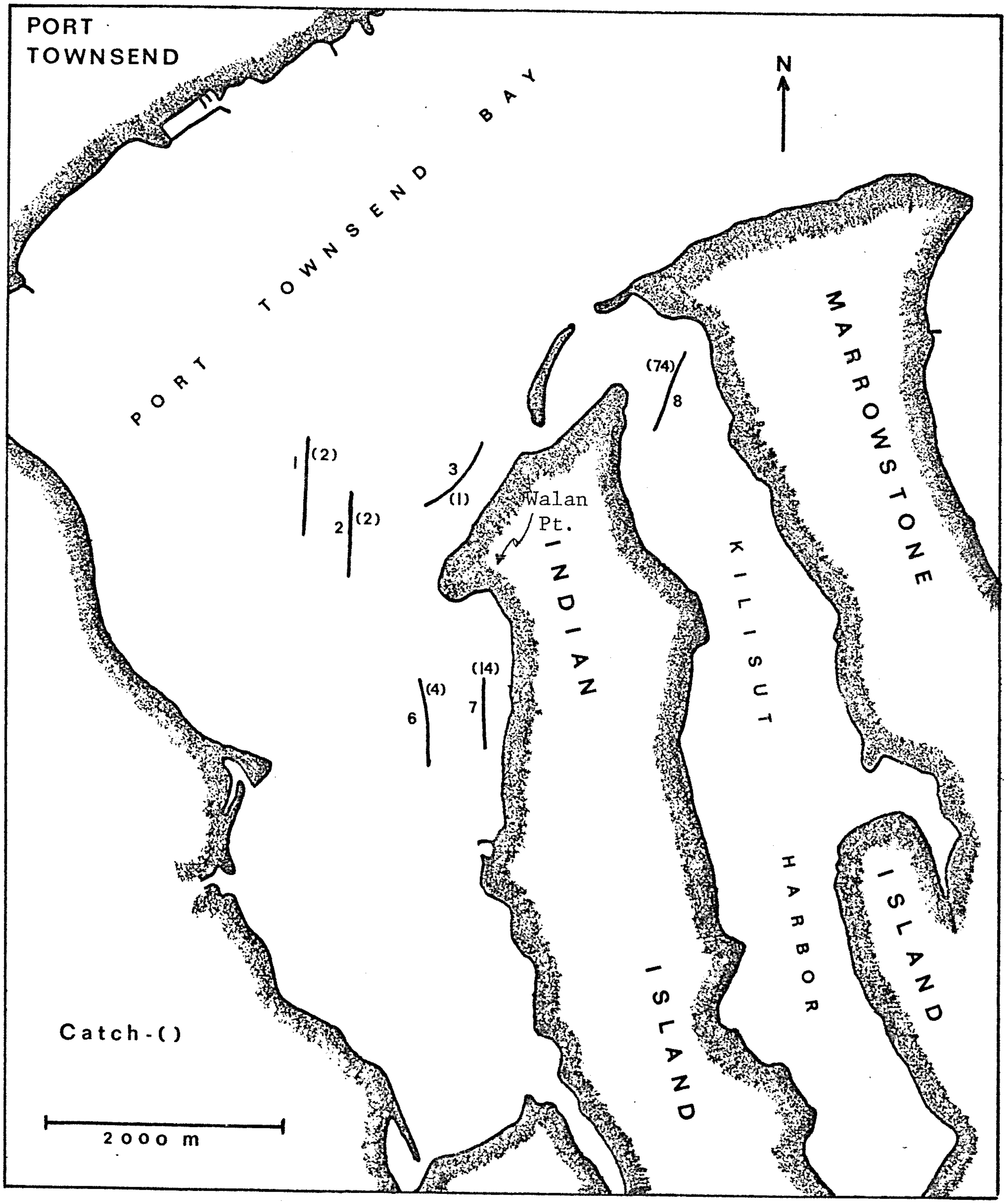

Fig. 12. Map of study area showing trynet stations sampled and juvenile gadid catches on 14 June 1977.

A total of 111 trynet hauls was carried out in 1978. Of these, 63 were conducted within Kilisut Harbor and 48 took place in Port Townsend Bay. Gadids were not encountered in trynet samples before 3 May 1978 (Table 7) when 59 juvenile gadids were captured; 50 of these were taken at 5 stations within Kilisut Harbor in water $\geq$ 8 m deep and the remaining 9 were sampled at station 10 in about 18 m of water, 1,000 m south of Walan Point (Fig. 13).

On 1 June, 241 juvenile gadids were captured at 6 stations. All were encountered in water $\geq$ 8 m deep (Fig. 14). Of the 2,220 juveniles sampled at 32 stations on 26 and 27 June (Fig. 15), 1,979 were found in water $\geq$ 8 m deep (Table 8).

Identification and measurements of the 1978 material are proceeding. Pacific tomcod (*Microgadus proximus*) and Pacific cod (*Gadus macrocephalus*) have been tentatively identified from the samples.

Temperature data obtained in Port Townsend Bay in 1977 and in Port Townsend Bay and Kilisut Harbor in 1978 indicated that temperatures in Port Townsend Bay were warmer in 1978 than in 1977 (Fig. 16). In late January 1977, water temperatures were less than 7°C at all depths whereas by early January 1978, the water column was already at 7.5°C. A greater degree of thermal stratification also was evident in 1978, particularly in April, May, and June. Surface and 10-m temperatures were one degree warmer (9°C) in mid-April 1978 than at the same time in the previous year. By mid-May 1978, temperatures at surface, 10 m, and bottom were 12.5°C, 10.5°C, and 9.5°C, compared with 9.7°C, 9.6°C, and 8.9°C in 1977.

Temperatures for Kilisut Harbor were recorded on four occasions in 1978 (Fig. 16). These waters were always warmer than those of Port

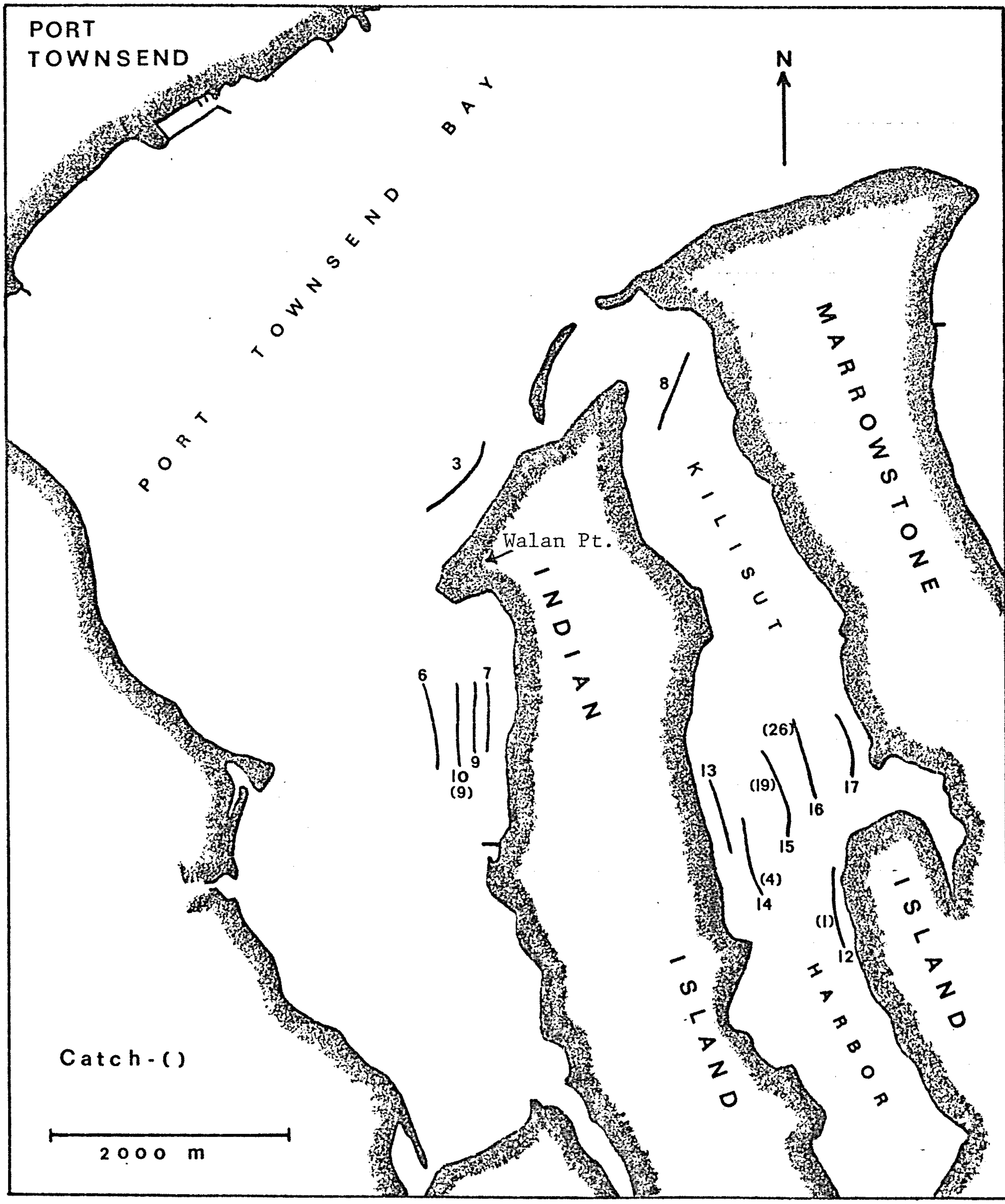

Fig. 13. Map of study area showing trynet stations sampled and juvenile gadid catches on 3 May 1978.

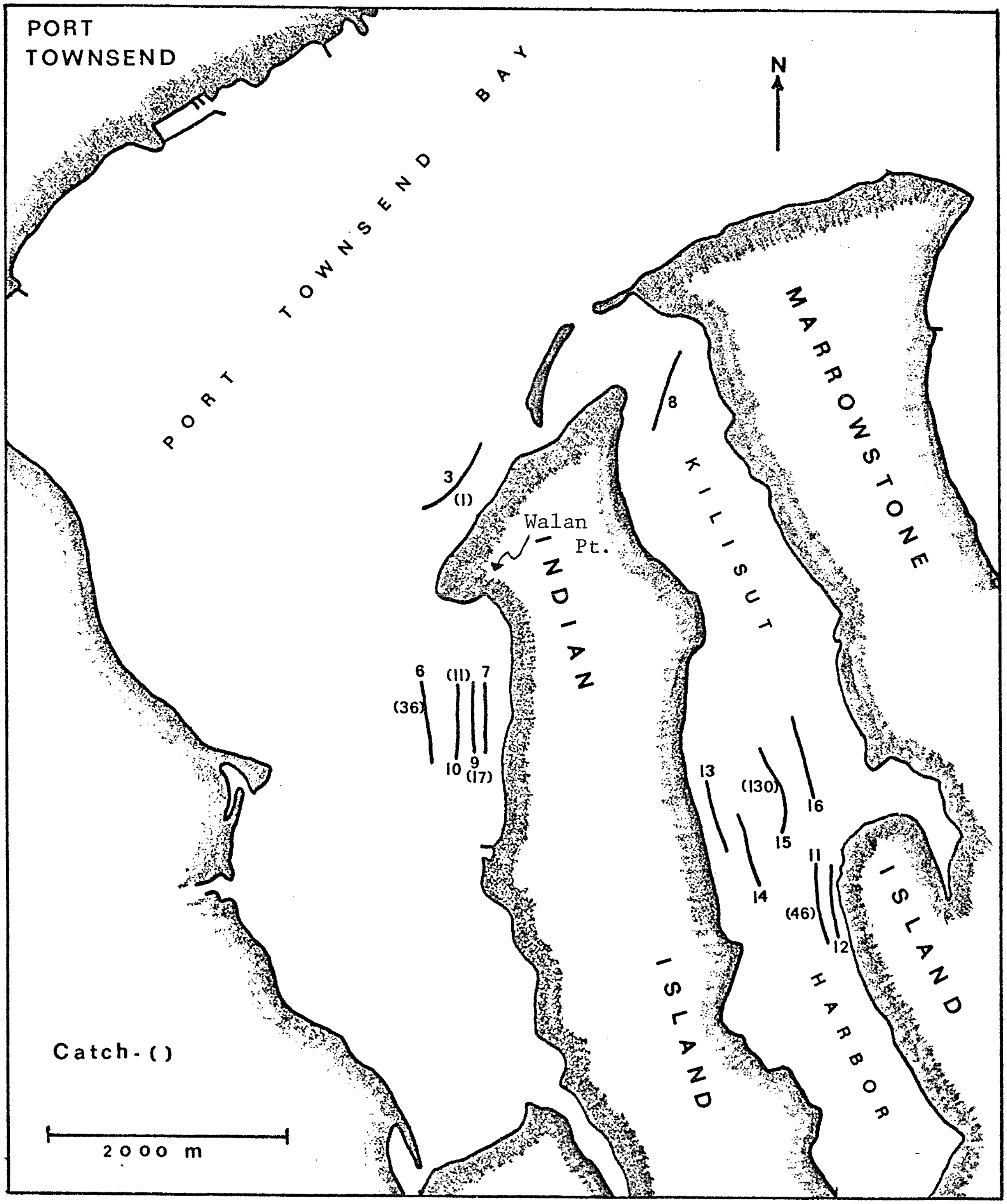

Fig. 14. Map of study area showing trynet stations sampled and juvenile gadid catches on 1 June 1978.

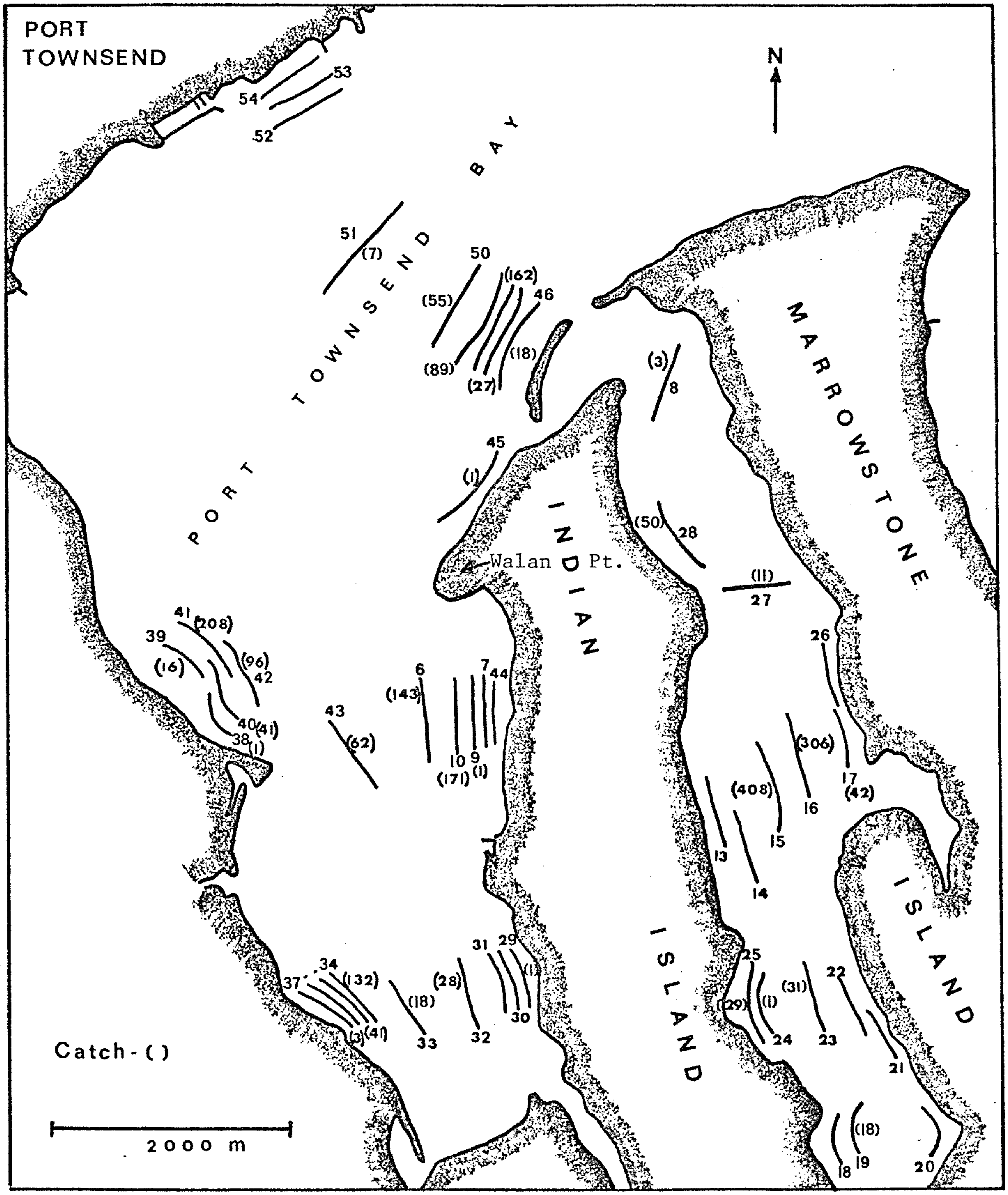

Fig. 15. Map of study area showing trynet stations sampled and juvenile gadid catches on 26-27 June 1978.

Table 8. Depth distribution of juvenile gadids sampled by trynet on 26-27 June 1978.

Location	Depth range (m)	No. of hauls	Catch (numbers)	Catch per haul
Kilisut Harbor	3-4	6	29	4.8
	5-7	7	95	13.6
	8-11	3	725	241.7
Port Townsend Bay	3-4	7	21	3.0
	5-7	6	96	16.0
	8-11	7	245	35.0
	12-20	6	635	105.8
	21-27	5	374	74.8

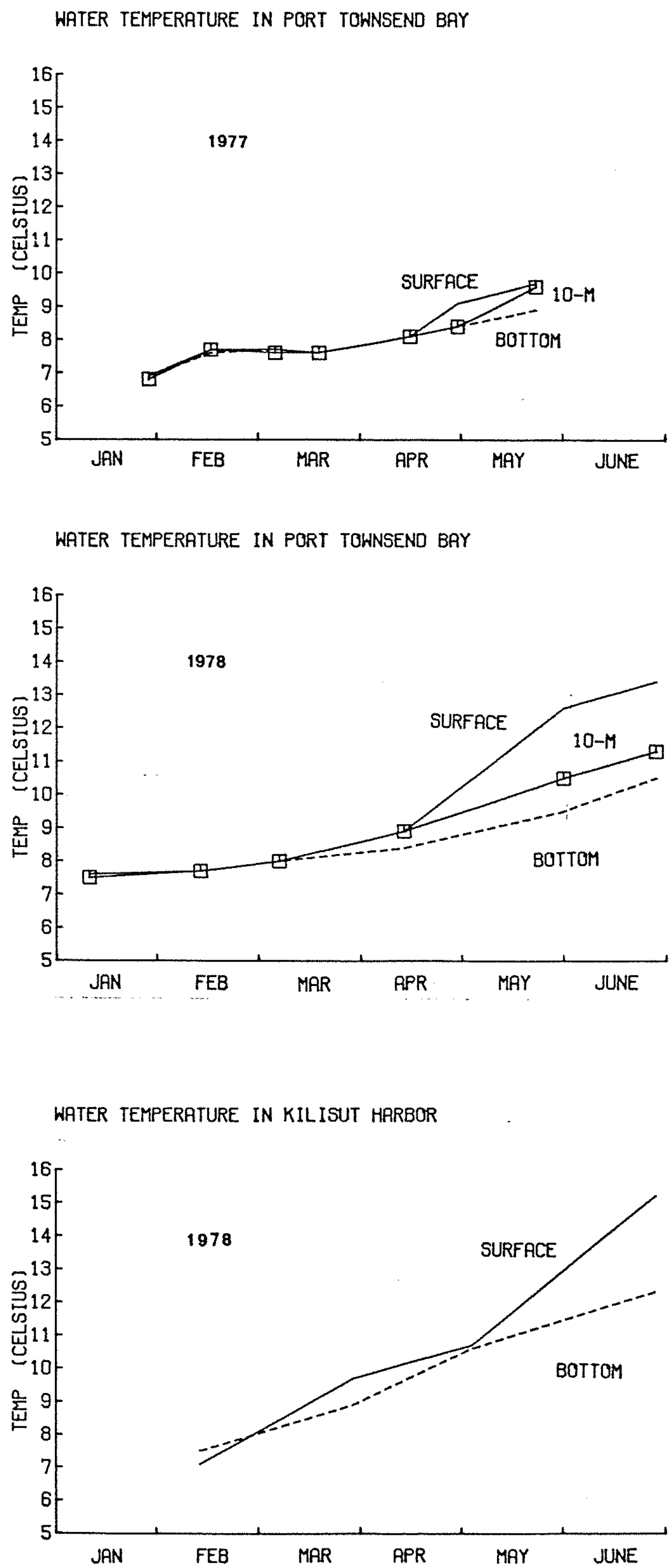

Fig. 16. Water temperatures in Port Townsend Bay 1977-1978 and Kilisut Harbor 1978.

Townsend Bay. Surface temperature increased from 7.1°C to 15.2°C during the period 12 February to 26 June. Bottom temperature increased from 7.5°C to 12.3°C during the same period.

3.3 Egg and Larval Surveys

Ichthyoplankton catches for 1977 and 1978 were summarized (Tables 9 and 10) and plotted by month and year for each station (Figs. 17 and 18). Some larvae were tentatively identified as young Pacific cod but are presented here as gadid larvae because of the difficulties of definitively separating the early life history stages of Pacific cod, tomcod (Microgadus proximus), and walleye pollock (Theragra chalcogramma).

In 1977 the highest abundances of fish eggs were observed at most stations on 25 February (Fig. 16). 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 15 April and 14 June. While trends and changes in estimated abundances of fish eggs were similar at stations 1, 2, and 3, the actual abundance estimates were 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 9). A general trend of decreasing fish egg abundance with time was apparent from the data.

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

Table 9. Ichthyoplankton catch summary for 1977.

Date	Station	Volume filtered (m^3)	# Eggs per 100 m^3	# Larvae per 100 m^3	# Gadid larvae per 100 m^3	Haul type
25 Feb.	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	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	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	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	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	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	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.

Table 10. Ichthyoplankton catch summary for 1978.

Date	Station	Volume filtered (m^3)	# Eggs per 100 m^3	# Larvae per 100 m^3	# Gadid larvae per 100 m^3	Haul type
6 Mar	1	192.9	1159.1	501.3	0.5	Surface
	2	138.3	523.5	135.2	0.0	Oblique
	3	209.9	27.6	40.5	0.5	"
	5	253.6	99.8	72.6	0.0	"
	6	222.6	13.5	22.5	0.9	"
	7	Not sampled				
28 Mar	1	193.6	125.5	209.2	13.9	Surface
	2	327.4	87.7	35.1	2.7	Oblique
	3	430.6	44.4	30.7	1.6	"
	5	233.5	163.6	49.7	2.1	"
	6	216.9	42.4	78.8	8.8	"
	7	121.6	446.5	342.9	0.8	"
13 Apr	1	408.7	167.6	141.4	23.0	Surface
	2	286.5	16.8	133.3	20.6	Oblique
	3	374.2	8.0	117.0	12.0	"
	5	377.6	40.0	114.1	18.5	"
	6	233.9	41.0	43.2	16.7	"
	7	Not sampled				
3 May	1	171.9	47.1	68.6	22.1	Surface
	2	214.6	33.6	11.2	3.7	Oblique
	3	132.3	22.7	32.8	1.5	"
	5	169.0	34.9	29.6	3.6	"
	6	102.6	20.5	82.8	29.2	"
	7	219.3	6.8	463.7	1.4	"
1 June	1	83.6	76.6	13.2	0.0	Surface
	2	275.2	5.5	8.0	1.8	Oblique
	3	Not sampled				
	5	Not sampled				
	6	119.2	20.1	5.9	2.5	Oblique
	7	113.4	7.9	7.9	7.1	"

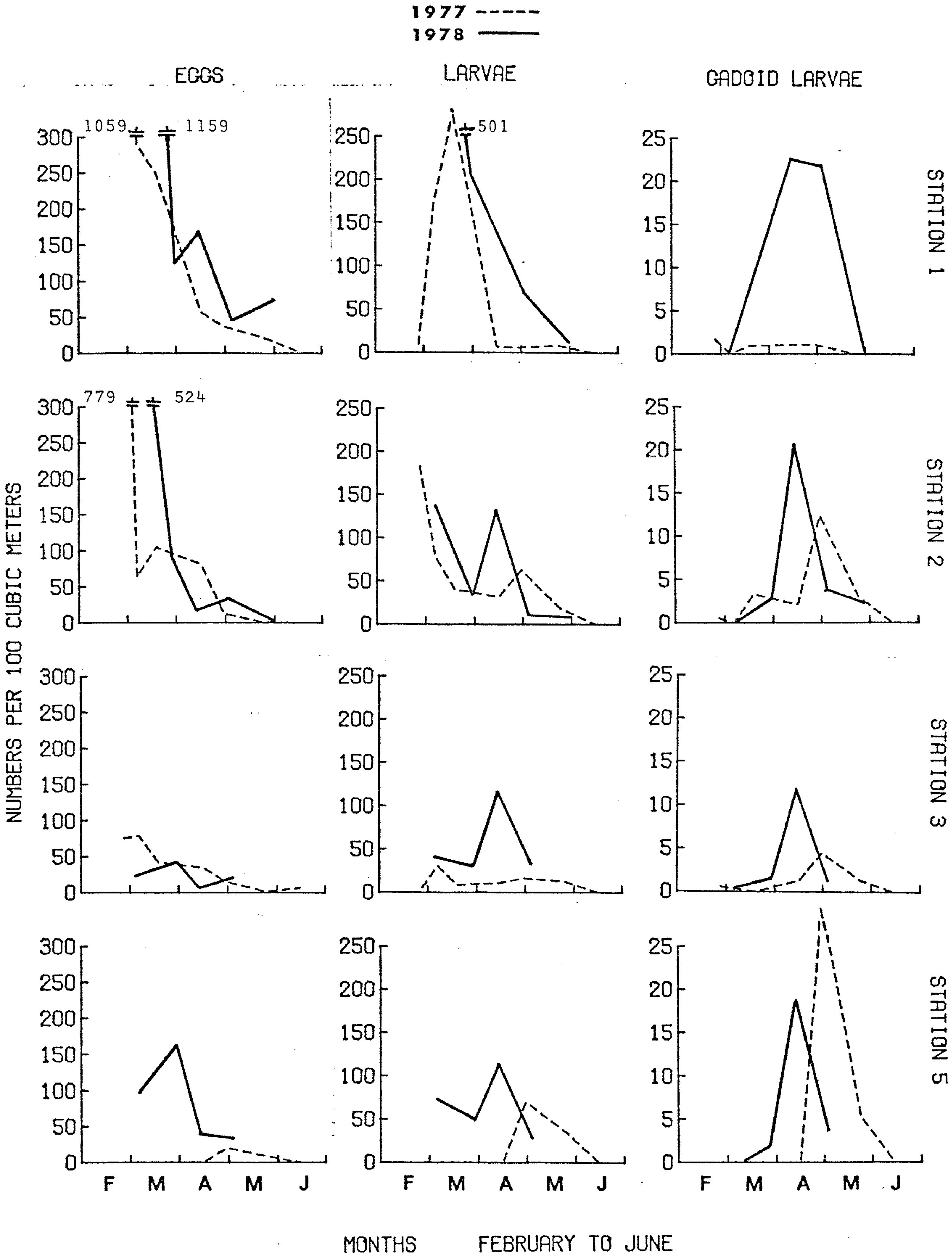

Fig. 17. Ichthyoplankton catches for stations 1-5 during 1977 and 1978.

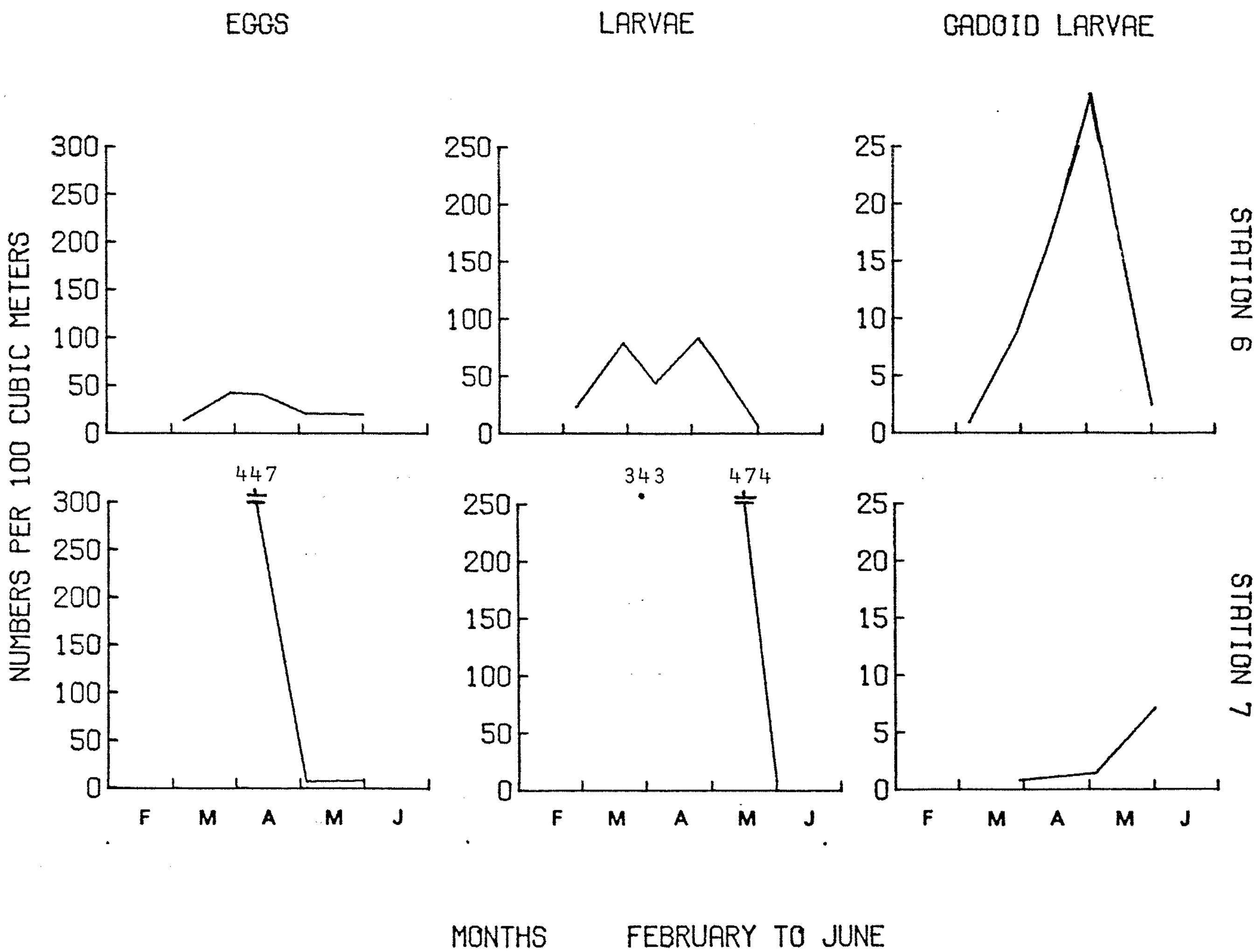

Fig. 18. Ichthyoplankton catches for stations 6-7 during 1978.

The two samples from station 5 showed parallel trends in abundance of total fish larvae and gadid larvae. Station 5 yielded the highest estimate of gadid larval abundance in 1977 on 24 April (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 gadid larvae at station 5 on 29 May were both higher than at the other stations.

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

Two additional ichthyoplankton stations were sampled in 1978. Station 6 sampled the southern margin of Mid-Channel Bank in about 21 m of water and station 7 sampled the water inside Kilisut Harbor at a similar depth (Fig. 1). Both stations were sampled with oblique hauls.

In 1978, estimates of egg abundance (Figs. 17 and 18) were greatest at station 1 on all occasions except 28 March when the estimate for station 7 was greatest. It should be repeated, however, that station 1 was sampled with a surface haul which would tend to catch more eggs than the oblique hauls conducted at the other stations. A general trend of decreasing egg abundance with time was evident from the data, although maximum abundance at stations 3, 5, and 6 did not occur until 28 March, the second sampling date. Much higher abundances of eggs were estimated at stations 1, 2, and 7 during the earlier sampling cruises than at other stations and times. Trends in egg abundance estimates were quite similar to those observed in 1977, except that density estimates for stations 1 and 2 were much greater in early March 1978 than during the same period in 1977.

Trends in abundance of total numbers of larvae (Figs. 17 and 18) were similar at stations 2, 3, and 5 in 1978. In each case, relative abundance estimates decreased between the first and second sampling dates (this decrease was more marked at station 2), increased to a peak by the mid-April sampling date, and then decreased with time (Fig. 17). Station 1 exhibited a very high abundance of larvae on 3 May ($501.3/m^3$) and then demonstrated a steady decrease in abundance with time. Station 6 exhibited two peaks of abundance, in late March and early May, with lower abundance estimates at intermediate times. Estimates of larval abundance at station 7 were high on 28 March, still higher on 3 May, and very low on 1 June (Table 10). Estimated levels of abundance of larvae were generally greater in 1978 than in 1977. In addition, trends in abundance were more consistent in 1978 than in 1977.

Trends in estimated abundance of gadid larvae were similar at all stations in 1978 (Figs. 17 and 18). They were highly consistent between stations 2, 3, and 5. Abundance of gadid larvae increased at all stations until mid-April, when peak estimates were obtained at stations 1, 2, 3, and 5. The highest level of gadid larval abundance occurred at station 6 in early May. Stations 1, 2, 3, 5, and 6 exhibited trends of decreased abundance with time after reaching their respective peaks. Estimates were low at most stations in early May, but not until early June at stations 1 and 6. Station 7 demonstrated a unique trend--a slow increase in abundance estimates from early April to early June. Estimates of abundance of gadid larvae were greater in 1978 than in 1977. As with the total larval estimates, peaks in abundance of gadid larvae occurred two weeks earlier in 1978 than in 1977.

3.4 Ultrasonic Tracking

Four successful tracks were obtained with ripe female cod. Track 1 (Fig. 19) was conducted on 19 February 1978. The fish moved from near the mouth of Kilisut Harbor to the Mid-Channel Bank where it remained during the afternoon. Near dusk the fish returned to near the original tagging site. Tracking operations were suspended on account of heavy fog. A search of the bay on the morning of 20 February failed to locate the fish.

Track 2 (Fig. 19) was conducted on 26 February. The pattern of movement was similar to track 1. The fish was lost because of engine battery failure on the tracking vessel. The next morning (27 February) the signal was picked up and traced to a commercial setnet near the mouth of Kilisut Harbor. The fish was recovered in good condition. Examination of the ovaries revealed that the fish still contained a substantial quantity of eggs.

Track 3 (Fig. 20) was completed on 5 March. The fish was captured near the dock area but was released northeast of the dock area to avoid the setnets. The fish moved slowly in the area for a short time and then quickly moved past Marrowstone Point into Admiralty Inlet. The fish then moved eastward into the center of Admiralty Inlet during the slack tide before moving quickly northwest with the strong outgoing tidal currents. Tracking was discontinued near Point Partridge on Whidbey Island when it appeared that the fish would not return to the general area of Port Townsend Bay.

Track 4 (Fig. 20) was completed on 8 March. The fish moved slowly north during the afternoon across the northwest end of the Mid-Channel Bank. Near dusk the fish moved around Point Wilson in the severe tide

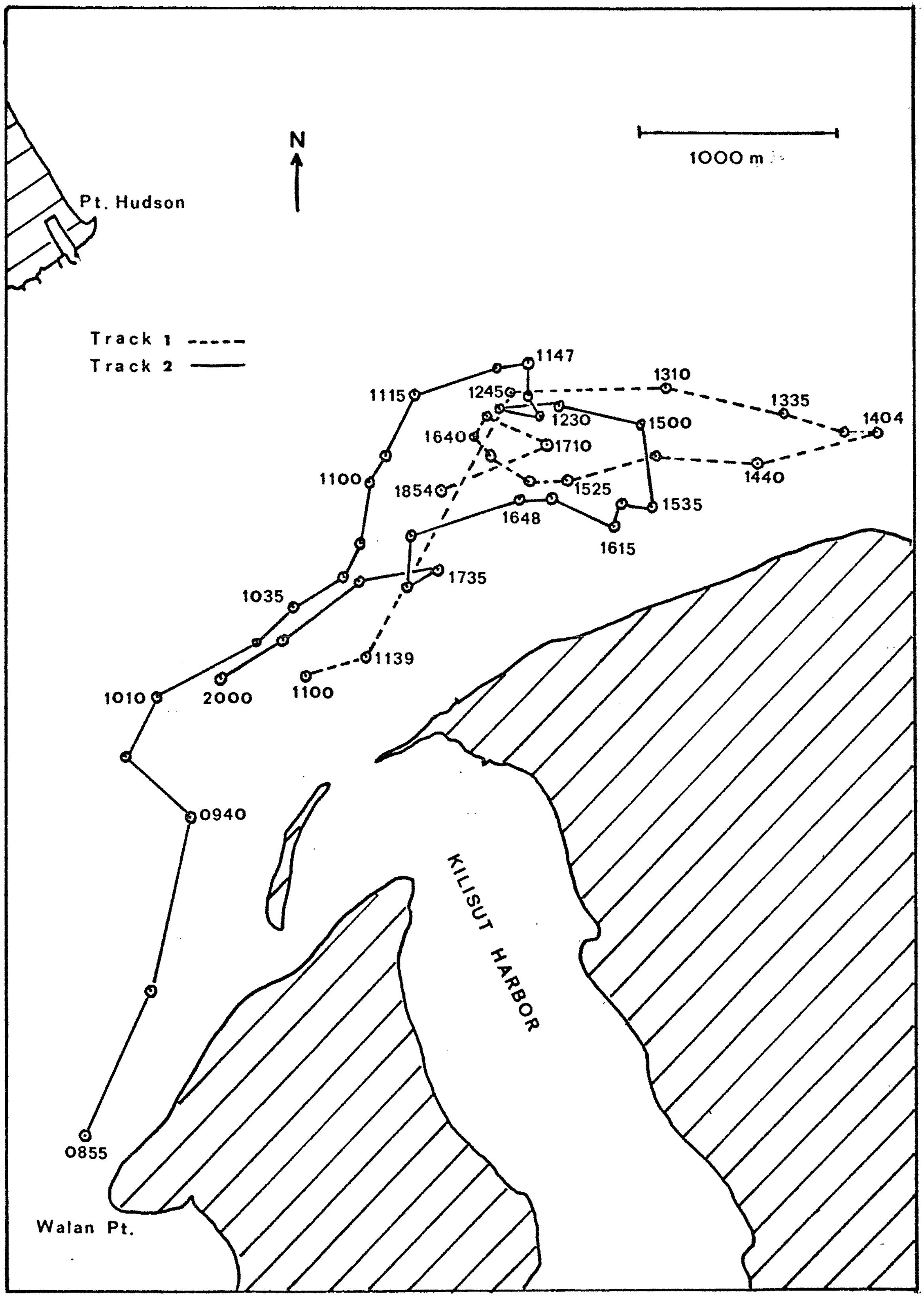

Fig. 19. Ultrasonic tracks 1 and 2, 19 February and 26 February 1978.

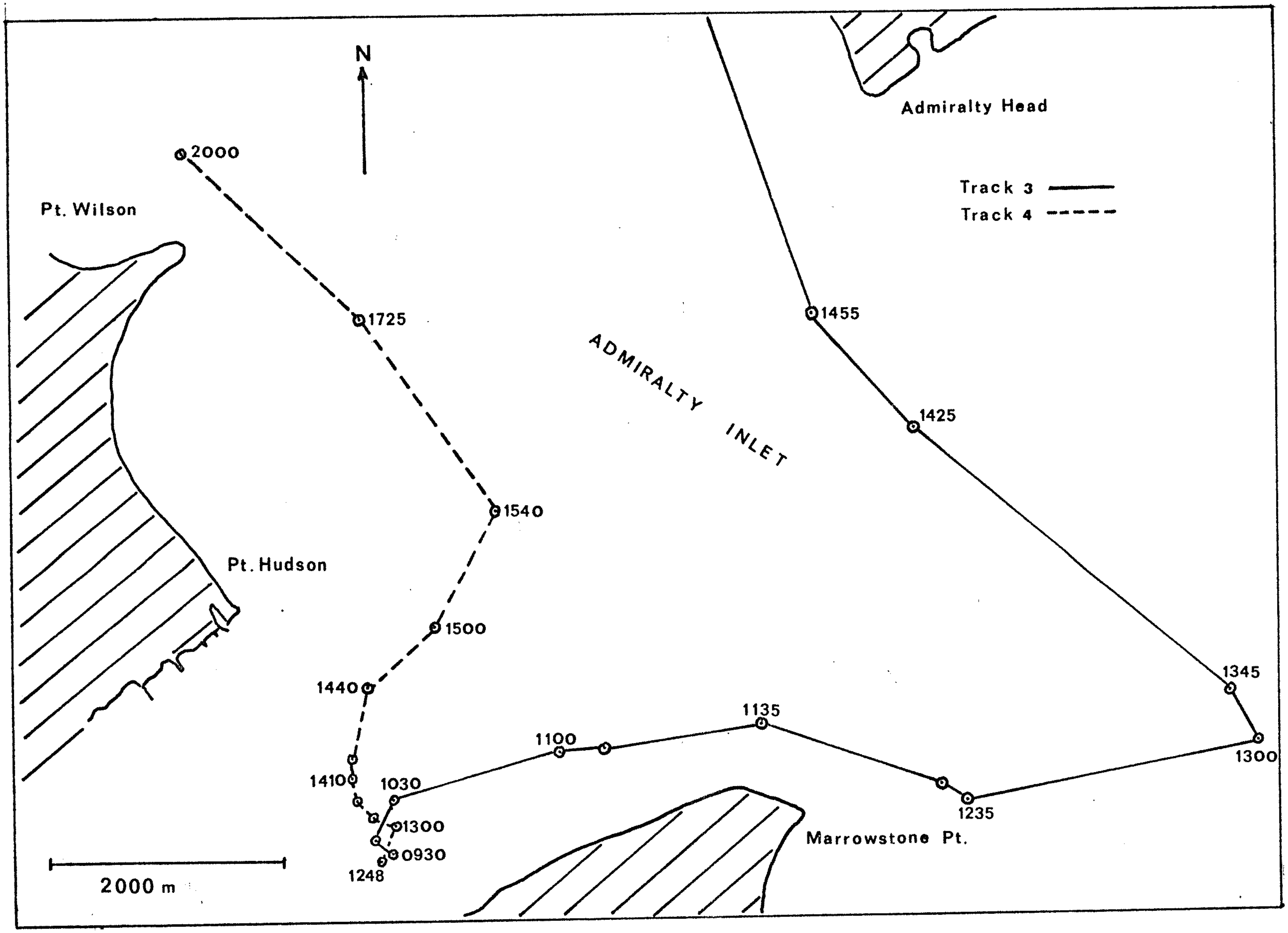

Fig. 20. Ultrasonic tracks 3 and 4, 5 March and 8 March 1978.

rips of the outgoing tide. The signal was lost in the high noise levels generated by the tidal currents.

Four additional attempts were made to track fish. In one case the fish was caught in a commercial setnet within one hour of release near the dock area. In three other cases the tags were believed to be regurgitated by the fish within a few minutes of release.

3.5 Diving Operations

Cod eggs were not observed during any of the dives in 1977 or 1978. Great care was taken to inspect the various sediment types encountered.

Two young (small) Pacific cod were observed during the night dive of 18 March 1977. A ripe and running female was observed in a setnet at the entrance to Kilisut Harbor on 5 March 1977. No other adult cod were observed during diving operations.

Other fish seen during diving in the area of the munitions dock in 1977 were ratfish, big skate, cabezon, staghorn sculpin, tubesnout, English sole, rock sole, starry flounder, shiner perch, and midshipmen. Cabezon egg masses were seen.

Diving operations were conducted on 1 March and 9 March 1978 in the vicinity of Mid-Channel Bank, close to the northwest tip of Marrowstone Island. Evidence of cod spawning was not observed. A dive in the Agate Pass area (Bainbridge Island) on 28 March 1978 was also unsuccessful in locating adult cod or evidence of spawning. Cabezon egg masses were also seen in Agate Pass.

3.6 Substrate Sampling

Eleven grab samples were taken in the Walan Point area on 5 March 1977. Bottom type was fine mud in all samples. Cod eggs were not detected in any sample.

3.7 Early Life History Studies

Attempts to rear larvae were not successful in 1977. In 1978, limited success was attained. Although larvae would not feed in the laboratory, a series of preserved specimens up to 13 days from hatching was obtained.

4. Discussion

4.1 Adult Fish

The adult fish data obtained in 1978 provided an improved basis for the description of the structure of the population, when compared with the 1977 observations. It was evident that research and commercial trawl data provided information on only a portion of the sizes of fish present. The setnet fishery provided information regarding the larger and older individuals, and the trynet sampled the young (juvenile) fish.

The average size of trawl-caught fish was similar in 1977 and 1978 (actually slightly larger in 1978). However, the CPUE for research trawling was much lower in 1978 than 1977.

The length frequency distributions presented by Ketchen (1961) demonstrated that larger Pacific cod were available to the commercial trawl fishery on the lower east side of Vancouver Island. However, larger fish were not caught by the trawl fishery in Port Townsend Bay. Although the setnet fishery consistently harvests larger fish, even before the setnet fishery was initiated, trawl landings included few larger individuals. This would seem to indicate 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 provided support for this argument--i.e., 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 setnet 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 Northwest Pacific (Moiseev 1953).

Almost all of the fish examined from the trawl catches were sexually mature. 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 rejection of smaller fish by the trawl operators probably resulted in an overestimate of average size of two-year-olds. In addition, an incomplete recruitment of two-year-olds is possible and would result in many of the immature fish of this age not being available to the fishery (S.J. Westrheim, pers. commun.). Nevertheless, it does appear that maturity occurs earlier in the Port Townsend Bay population than elsewhere. Most of the females in the Port Townsend Bay catches 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 mm for western Kamchatkan fish (Moiseev 1953).

The length-weight relationships demonstrated a high degree of consistency between the different groups of fish sampled. In all cases the exponent was close to 3.0, indicating isometric growth. Very similar length-weight relationships have been developed for Canadian (Forrester 1969) and West Pacific (Moiseev 1953) populations (Table 11). Some of the differences might be due to time of capture--i.e., prespawning or postspawning. There is, nevertheless, an indication

Table 11. Comparison of length-weight relationships and computed weights at length for Pacific cod from several locations.

	Coefficients from $W = aL^b$		Lengths (mm)							
Source	a	b	200	300	400	500	600	700	800	n
All Port Townsend 1977 + 1978	3.171×10^{-6}	3.200	73	268	672	1372	2459	4027		1271
Hecate Strait (Forrester 1969)	2.050×10^{-5}	3.431	60	240	643	1383	2585	4389		181
Gulf of Georgia (Forrester 1969)	2.148×10^{-4}	2.820	100	314	707	1327	2214	3427		182
Sea of Japan (Moiseev 1953)	6.130×10^{-6}	3.146		272	673	1357	2409	3913	5956	1471*
Sea of Okhotsk (Moiseev 1953)	3.598×10^{-6}	3.275		248	636	1320	2399	3974	6155	1645*
Bering Sea (Moiseev 1953)	1.398×10^{-5}	2.956			761	1471	2521	3977	5901	3158*

*Moiseev provided only mean weights for length classes; relationships were computed from these figures.

that the Bering Sea Pacific cod have a reduced rate of weight increase at greater lengths compared with populations from warmer, more southerly waters in the Eastern and Western Pacific. Moiseev's (1953) data for the Bering Sea, the Sea of Japan, and the Sea of Okhotsk indicated that Pacific cod in these regions reach much greater sizes than are encountered in British Columbia and Washington waters. However, their lifespans are also much greater.

The age data analysis is not yet adequate to explain patterns of growth in Port Townsend Pacific cod. Instead, a comparison of the available Port Townsend Bay information with published length at age statistics for other populations of Pacific cod was made (Table 12). When compared with statistics for Strait of Georgia and Hecate Strait populations, the Port Townsend Pacific cod appeared to have a slightly slower growth rate, although it should be noted that the length at age V is derived from only one observation at Port Townsend and that the age II fish were probably incompletely sampled. The most marked contrast was between Eastern and Western Pacific populations. Growth rates were generally much slower in the Western Pacific, particularly in the more northern populations, although the maximum age and size are much greater among Western Pacific populations of Pacific cod.

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 in greater detail until further length-at-age observations are made.

The stomach-content analysis work indicated that crustaceans (mainly shrimp) and small fish were preferred food items. The work of Hart (1949) in British Columbia coastal waters supported these

Table 12. Comparison of mean length at age for Pacific cod from different locations.

Source	Age: I	II	III	IV	V	VI	VII	VIII
Strait of Georgia (Ketchen 1961)	261	499	614	673	726	762		
Hecate Strait (Ketchen 1964)	260	435	552	642	711	764	805	836
Hecate Strait (Ketchen 1970)		542	582	662	746	758	810	
Port Townsend 1977 (This study)	255	435	473	602	720			
W. Kamchatka (Sea of Okhotsk) (Moiseev 1953)		318	377	461	558	670	752	833
Tatarsky Strait (Sea of Japan) (Moiseev 1953)		348	437	530	625	700	758	831
E. Kamchatka (Bering Sea) (Moiseev 1953)	181	307	413	499	573	634	684	739

observations. Suyehiro (1934) also found crustaceans to be the predominant food item 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. Quast (1966) reported that pollock (Theragra chalcogramma) was the chief food of Pacific cod in some localities. 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. Crepuscular feeding activity was possibly indicated by the data.

Three relationships have been developed to describe the fecundity of Pacific cod (Tables 13 and 14). Ketchen (1961) derived a relationship from the work of Moiseev (1953) for observations conducted in Kamchatkan waters. Ketchen used this relationship for his data from Nanoose Bay, Strait of Georgia, British Columbia. Thompson (1962) determined a length-fecundity relationship for Pacific cod from Hecate Strait, British Columbia.

Ketchen fitted an exponential ($y = a\ e^{bL}$) model to Moiseev's data, whereas Thompson utilized the more conventional power curve ($Y = aL^b$) which was also used in this study. The estimates obtained from Moiseev's and Thompson's data are similar for fish in the 60 to 70 cm length range, but at greater lengths Hecate Strait fish appear to have greater fecundities than those from Kamchatka. The data from Port Townsend Bay yield higher estimates of fecundity at all comparable lengths than the Kamchatkan and Canadian material. Thus, there is an indication of increase in size-specific fecundity with increase in water temperature, which was also observed by Moiseev (1953). This phenomenon would

Table 13. Comparison of length-fecundity relationships and estimated annual egg production of 1,000 typical females for Pacific cod from different locations.

Stock location	Source of data	Relationship	Est. ann. egg prod. of 1,000 fish
West coast of Kamchatka	Moiseev 1953 (adapted by Ketchen 1961)	$\log_{10}F=0.0135L + 5.370$ (Ketchen from Moiseev)	2.93×10^9
Nanoose Bay, Strait of Georgia	Ketchen 1961	$\log_{10}F=0.0135L + 5.370$	1.64×10^9
Nanoose Bay, Strait of Georgia	Ketchen 1961	$F=(9.02x10^{-5})(L^{(3.6415)})$ (Thompson)	1.38×10^9
Nanoose Bay, Strait of Georgia	Ketchen 1961	$F=(1.3217x10^{-2})(TL^{(2.9589)})$ (This study)	2.48×10^9
Hecate Strait	Thompson 1962	$F=(9.02x10^{-5})(L^{(3.6415)})$	1.38×10^9
Port Townsend Bay	This study	$F=(1.3217x10^{-2})(TL^{(2.9589)})$	1.49×10^9

Table 14. Estimates of fecundity at length for different fecundity relationships.

Length (mm)	$\log_{10}F=0.0135L+5.370$	$F=(9.02x10^{-5})(L^{(3.6415)})$	$F=(1.3217x10^{-2})L^{(2.9589)}$
400	(8.128×10^5)*	2.695×10^5	6.613×10^5
500	(1.109×10^6)	6.074×10^5	1.280×10^6
600	1.514×10^6	1.180×10^6	2.195×10^6
700	2.065×10^6	2.068×10^6	3.463×10^6
800	2.818×10^6	3.364×10^6	(5.141×10^6)
900	3.846×10^6	(5.165×10^6)	(7.285×10^6)
1,000	5.248×10^6	(7.581×10^6)	(9.950×10^6)

*Note that figures in parentheses refer to estimates outside the range of lengths from which the relationships were derived.

provide a measure of compensation for the southern populations which grow, mature, and die at faster rates than their northern counterparts; even though a Port Townsend Bay fish spawns fewer times and at a smaller size than one in the waters of Kamchatka, an adequate number of eggs would be produced. This can be seen more clearly by comparing estimates of annual egg production by 1,000 mature females (Table 13). Estimates were obtained using appropriate lengths of mature fish from Kamchatka and Nanoose Bay (Ketchen 1961), Hecate Strait (Thompson 1962), and Port Townsend Bay. Egg production estimates were substantially higher for the west coast of Kamchatka where mean size and age were much greater. Estimates for Nanoose Bay, Hecate Strait, and Port Townsend Bay were similar although the selection of an appropriate relationship would be important. Rass (1941, in Moiseev 1953) suggested that egg size decreased southward, thus facilitating an increase in weight-specific fecundity in populations which mature earlier. There was circumstantial evidence for this in the relationships presented.

4.2 Juveniles, Eggs, and Larvae

The trynet catches of juveniles provided valuable data on their distribution in Kilisut Harbor and throughout Port Townsend Bay. The 1977 data indicated that Pacific cod utilized areas around Indian Island as a nursery area. When the analysis of the 1978 data is completed it will further define the importance of these areas for Pacific cod. Monthly sampling trips are planned through the end of 1978 to monitor the growth and distribution of the 1978 year class. It has already become obvious that this population of Pacific cod spends a considerable part of its early life within the bay. Since the survival of these juvenile stages is often a significant factor in determining recruitment into a commercial fishery, these areas may be of vital importance to the Port Townsend Bay Pacific cod fisheries.

The ichthyoplankton data provided some insight into the importance of the study areas as spawning and rearing sites for fish. The very high abundances of eggs and larvae at the southern approach to Kilisut Harbor (station 1) in both years indicated that the harbor was probably an important rearing area for several species of fish. Many of the larvae sampled in March and April were baitfish species, which was not surprising since a substantial spawning of Pacific herring has taken place in southern Kilisut Harbor for many years.

Stations 1 and 2 demonstrated comparable trends in egg abundance in 1977 and 1978. The very high estimates of egg abundance at station 1 were partly a result of the surface hauls conducted at that site. Lower estimates of abundance of eggs at stations 5 and 6 suggested more mixing of the water mass in these areas. The high egg abundance estimate in late March 1978 in Kilisut Harbor (station 7) also supported the argument that Kilisut Harbor is important to the early life history of many species. The general trend of maximum egg abundance early in the season with a steady decline during the succeeding months was apparent in all the data, although in 1978 maximum abundances at stations 3, 5, and 6 did not occur until mid-March.

There were some similarities in the trends of estimates of abundance of larvae between years. Stations 2 and 3 (Walan Point area) each showed two peaks of abundance in each year, although the second peaks were higher in 1978 and also occurred about two weeks earlier. Possibly this was related to the increased temperatures in the bay in 1978. Station 6, in northern Port Townsend Bay, was not sampled in 1977; trends in abundance of larvae at station 6 were different from those observed elsewhere in 1978. Peaks of abundance occurred in late March and early May when low levels of abundance were observed at stations 2, 3, and 5. The location of station 6 was somewhat remote from the other stations and under a greater degree of influence from the waters of Admiralty Inlet. Station 7, in central Kilisut Harbor, was sampled on three occasions in 1978. This station is close to the Pacific herring spawning grounds in Kilisut Harbor, which accounted for the very high concentration of larvae (mostly herring) in early May.

The peak of gadid larval abundance generally occurred in mid- and late April of both 1977 and 1978. Estimates of abundance of gadid larvae were generally greater in 1978 than in 1977. Estimates of abundance of gadid larvae at station 1 (Kilisut Harbor entrance) were much greater in 1978, although trends in abundance of gadid larvae were similar for each year at the stations near Walan Point (stations 1, 2, and 3). Station 6, at the mouth of Port Townsend Bay, yielded high estimates of gadid larval abundance in mid-April and early May. Levels were generally low at station 7 (middle Kilisut Harbor) on the occasions when that location was sampled.

The problem of taxonomy remains. Some Pacific cod larvae are now available from the rearing work and it is hoped that with careful laboratory work the gadid species can be separated from the samples. However, the relatively low estimates of abundance of gadid larvae, together with the very high estimates of egg production by Pacific cod leave much room for speculation regarding the location of spawning, the distribution of the larvae, and the mortality influences on these stages.

4.3 Location of Spawning Grounds

The purpose of the ultrasonic tracking was to attempt to locate the cod spawning area. No localized spawning area was discovered. In the first two tracks, the fish moved over the Mid-Channel Bank during daylight hours and back to the dock area at night. Diving operations over the bank on 1 March found no evidence of eggs. The Walan Point area was searched by grab sampling and by divers during the 1977 study and no eggs were found. The last two ultrasonic tracks suggested extensive movement of fish both within the bay and in the surrounding waters. It is possible that a localized spawning area does not exist--rather, spawning may be taking place over a large part of the bay in a random manner. However, Kilisut Harbor is a possible spawning area which should be examined more thoroughly in the future.

5. Recommendations

a. Our work indicates that it would be useful to sample as close to the bottom as possible for cod eggs and larvae; the National Marine Fisheries Service has offered the use of a Tucker trawl equipped with a sled for sampling very close to the bottom. We are also designing an array of anchored plankton nets which could be used to sample specific depth strata for varying periods of time. Our sampling would emphasize the Kilisut Harbor - Walan Point area.

b. Identification of larvae continues to be a major obstacle in defining the distribution of the early stages of Pacific cod. Rearing attempts should be continued.

c. Evidence from the ichthyoplankton work, the trynet studies, and the commercial fishery suggests that Kilisut Harbor may play an important role in the life history of Port Townsend Bay Pacific cod.

Investigations should be intensified, especially during the spawning period.

d. The trynet sampling should be continued, on a monthly basis, throughout the year in order to document seasonal changes in the distribution and abundance of the juveniles and to provide growth information. Fish remaining within the study area for the year will be most susceptible to environmental changes in the bay.

e. Trawl and setnet catch information indicates that the distribution of adult fish in the bay is segregated by size. The use of experimental, variable mesh gillnets would provide specific information regarding this size distribution, and would therefore be especially valuable when it becomes necessary to compare the importance of different areas within the bay to each of the fisheries. The use of gillnets could also allow us to determine the location and direction of movement of running and spent fish.

f. A mark recapture study would provide information regarding distribution and movement of adult fish in the area and would allow estimates of population size, fishing mortality, and vulnerability to each gear type to be estimated. Such studies would make a substantial contribution to our knowledge of the Port Townsend Bay Pacific cod population which would allow us to reach a greater understanding of the influences of fishing and environmental changes on the population.

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.

Alverson, D.L. 1968. Fishery resources in the Northeast Pacific Ocean. Univ. Washington Publs. Fish. 4:86-100.

Cobb, J.N. 1916. Pacific cod fisheries. Rept. U.S. Comm. Fish. for 1915, Appendix IV.

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

Dalen, J. 1974. Experiments with acoustic tags in Lofoten in March 1974. (in Norwegian) Fiskets Gang 60(23):433-436.

Fisheries and Environment Canada. 1978. Annual summary of British Columbia catch statistics, 1977. 22 pp.

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. 1969. Life history information on some groundfish species. Fish. Res. Board Can. Tech. Rept. 105, 17 pp.

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. 19, 42 pp.

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

Hawkins, A.D., D.N. MacLennan, G.G. Urquhart, and C. Robb. 1974. Tracking cod Gadus morhua L. in a Scottish sea loch. J. Fish Biol. 6:225-236.

Karp, W.A., and B.S. Miller. 1977. Pacific cod (Gadus macrocephalus) studies in Port Townsend Bay, Washington. Univ. Washington, Coll. Fish., Fish. Res. Inst., Circ. FRI-UW-7723, 39 pp.

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.

Quast, J.C. 1966. The Pacific cod systematic relationships, biology and fishery. Pp. 245-254 in J. Malaurie, ed., Géoéconomie de la morhue. Mouton et Cie, Paris.

Schultz, L.P., and A.D. Welander. 1935. A review of the cods of the N.E. Pacific with comparative notes on related species. Copeia 35(3):127-139.

Smith, R.T. 1936. Report on the Puget Sound otter trawl investigations. State of Washington, Department of Fisheries, Biological Report No. 36B, 61 pp.

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

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

Svetovidov, A.N. 1948. Fauna of the USSR. Fishes. Vol. IX, No. 4, Gadiformes, 304 pp. (Trans. National Science Foundation, Washington, D.C.)

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.

Washington Department of Fisheries (WDF). 1975. 1975 fisheries statistical report, 115 pp.

Wilimovsky, N.J., A. Peden, and J. Peppar. 1967. Systematics of six demersal fishes of the North Pacific Ocean. Fish. Res. Board Can. Tech. Rept. 34, 95 pp.

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.).