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Biology of ocean age 0 Hatchery, Wild Ocean, and Wild Stream Type Chinook in the Strait of Georgia

by:

R.J. Beamish and Z. Zhang

Department of Fisheries and Oceans
Science Branch
pacific Biological Station
Nanaimo, B.C. V9R 5K6
CANADA

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Abstract

The pattern of otolith daily increments was used to study the first year of ocean residence of hatchery-reared, wild ocean, and wild stream type chinook. Several checks of the accuracy of the otolith estimates of life history and rearing types indicate that the determinations appeared reliable. There was a gradual decline in the percentage of hatchery fish in the catches that approached a percentage between 50-65% by the end of the year, depending on the assumptions made. The three rearing and life history types were distributed throughout the strait and to depths ranging from 40-60 m. The mean size differences that existed in the early samples, persisted throughout the year, but based on one sample of fish older than ocean age 0, the mean sizes of the three types may eventually be about equal. Wild stream-type juveniles remained in the strait and were more abundant relative to wild ocean type juveniles than in the past. One reason for this is the large number of ocean type hatchery fish that are now part of the total population. Diet studies indicated that the three rearing and life history types fed on similar prey, except that wild ocean type juveniles may consume less fish in their first ocean year than the other types.

Introduction

Wild chinook salmon (*Oncorhynchus tshawytscha*) have two distinct life history types, the stream type and the ocean type that Healey (1991) proposes are distinct races. The young of the stream type remain in fresh water longer than the ocean type and consequently are larger when they enter salt water. The adults of the stream type tend to return to fresh water earlier than the ocean type and they remain in fresh water longer than the ocean type before spawning. Within the Strait of Georgia, Healey (1980, 1991) reported that the stream type entered salt water first and dispersed seaward as the ocean type were moving into the nearshore areas. In the open waters of the Strait of Georgia, Healey reported that there was a gradual change in the composition of the catches as the stream type became less abundant in the fall. There was no evidence of a migration of ocean type chinook out of the strait before November (1976). The reported behaviour of these two rearing types, therefore, can be summarized as an early movement of the stream type into salt water, a gradual movement into the open waters of the Strait of Georgia by summer, and out of the strait by fall. Ocean type wild fish, enter salt water later and remain in the nearshore areas longer, with some remaining throughout the winter.

Beginning in the 1970s and throughout the 1980s and 1990s, hatchery-reared chinook have been added to the Strait of Georgia in increasing numbers. In the mid-1970s, approximately 2.5 million hatchery-reared smolts were released into the strait and by the early 1990s, the number had reached approximately 41 million (Beamish et al 1995). Beamish et al. (1995) estimated that the number of hatchery smolts released in the early 1990s was equivalent to the number of wild smolts and the total of approximately 82 million was between 2-3 times the number of wild chinook smolts that entered the strait at the time of Healey's studies in the 1970s. Virtually all of the hatchery smolts are the ocean type, thus, a substantial number of this rearing type have been added to the populations of wild ocean and wild stream type.

In this study, we report the preliminary results of the first studies of the biology and behaviour of juveniles of these three rearing and life history types in the Strait of Georgia. We use the pattern of daily growth zones on the otolith to identify the hatchery, wild ocean, and wild stream type life history and rearing types. We also use sampling gear that facilitated the study of chinook salmon throughout the year and throughout the water column. The results are preliminary because the study is designed to last through to the end of 1998.

Methods

Fishing Gear:

We used beam trawls to capture smolts when they first entered salt water. A rope trawl was used for the first time in April and July and a modification of this net was used in the September and November cruises. When fishing to design specifications the modified net will fish 21.3 m deep and 63.5 m wide. The first 54.3 m of the net, or the front end, consists of large rope meshes that can range from a minimum of less than 2 m in width to over 3.8 m. The intermediate portion has meshes ranging from 1.6 m to 20 cm. The cod end has 10 cm meshes with a 1 cm liner in the last 7.6 m of the net. The net is held open with USA Jet Doors Model P that can be hooked up to fish at the surface or any depth. The specified bridle length is 61 m, but we used 30.5 m to fish the net at the surface. This shorter bridle length reduced the opening of the net to approximately 14 m deep by 28 m wide, but the size and shape of the opening varied according to tides and sea conditions. When the doors were at the surface, the head rope was between the surface and 3.5 m. A Simrad TS3300 net sounder was attached near the head rope and provided a continuous image of the net opening, large schools of fish that were entering the net, and a continuous indication of head rope depth.

Survey Design

The beam trawls were fished continuously at a speed of 3 knots while the rope trawls were fish for either 1/2 hour or 1 hour at an average speed of 4 - 5.2 knots. The survey design for beam trawls represented a series of track lines that were distributed within the Strait of Georgia so that chinook were collected from areas of known abundance, as well as sampling in the center and both sides of the strait. We attempted to collect samples of 200-400 chinook in each cruise, but we considered it more important to sample throughout the strait than to obtain large catches from one area. Early in the year, sets were made during daylight hours because the young salmon were in the surface waters and readily captured. In July, the beam trawl survey was carried out at night because earlier studies showed that catches were substantially higher at night. All rope trawls were made during daylight hours because the large net could readily be fished at all depths. The amount of daily effort was limited to 12 hours because of controls on the hours that the crew could work.

Identification of Hatchery and Wild Juveniles

The chinook smolts that were collected were identified as hatchery-reared or wild using the pattern of daily growth in the otoliths (Zhang et al., 1995). All otoliths increase in size by producing a daily increment with two zones (Pannella, 1971). One zone contains more protein than the other and appears darker when viewed with a microscope using transmitted light (Campana and Neilson, 1985; Zhang, 1992). The otoliths from fish that were tagged with a coded wire tag (CWT) when released from the hatchery were identified using the otolith method without the knowledge that the fish had a CWT. The accuracy of the determinations of hatchery fish was then estimated using these otoliths.

Results

Most of the juveniles sampled in 1995 were from the 1994 spawning brood year (Table 1). When they entered salt water in 1995, they were in their first year of life and did not have an annulus on the otolith. The stream type wild fish were hatched in 1993 and remained in fresh water for one year where they formed one freshwater annulus on the otolith. There also was a sample of older chinook collected in late April 1995, using the rope trawl. This sample did not contain any smolts as few chinook salmon smolts had entered the strait at this time.

Identification of hatchery and wild, ocean-typed and stream-typed chinook

Otolith daily growth increments deposited in the hatchery after exogenous feeding (after yolk sac absorption) appeared regular in width and contrast, while daily growth increments produced in the fresh water after exogenous feeding in otoliths of wild chinook were more variable in width and contrast. The contrast results from the deposition of protein and the resulting changes in light intensity using transmitted light. Shortly after the hatchery-reared fish are released into the wild, growth increments usually become relatively irregular. Upon entry into the ocean, both hatchery-reared and wild chinook produced wide and regular growth increments.

The otoliths of stream-type chinook were easily separated from ocean type fish by the larger number of daily increments and an annulus (Table 2). There were a variable number of 40-100 wide and prominent increments that could be counted, followed by numerous, narrow and hard-to-identify increments that were not possible to count. A distinct hyaline zone or annulus formed in most of the wild stream-type chinook otoliths (86%). Distal from the hyaline zone, were increments that were wide and regular, indicating that the fish had entered the ocean. Ocean-type wild chinook otoliths had fewer freshwater increments and did not contain a hyaline zone in the freshwater growth period. Hatchery-reared ocean-type chinook, growth increments were uniform in appearance for the period of rearing in the hatchery, then became narrower and irregular prior to entry into salt water.

Very few stream type chinook are reared in hatcheries. Samples in our catches had the characteristic pattern of growth of hatchery ocean type fish after the onset of exogenous feeding, but only 1/3 had a hyaline zone in the winter that characterized wild stream type otoliths. The accuracy of the classifications of this rearing type was poor. Only one of 4 CWT fish was identified correctly as a stream-type, hatchery reared fish and the other three were misidentified as wild fish. However, the four fish were all correctly identified as stream-type chinook. A re-examination of the hatchery reared stream type otoliths identified differences in the microstructure, but these differences were only apparent after it was known that these hatchery fish were stream types. However, because this rearing type represents less than 5% of the hatchery fish produced, the errors are not considered important.

Among the samples collected in the Strait of Georgia in 1995, there were 157 chinook which were coded-wire-tagged in the hatchery, 140 were correctly identified as hatchery-reared fish, 15 were misidentified as wild fish and 2 were not identified due to crystalline otolith structure. No ocean type, CWT chinook were misidentified as stream type. Thus, the accuracy of identifying salmon smolts known to have been released from hatcheries was approximately 90%.

CWT estimate of the percentages of rearing types

It is possible to estimate the percentage of hatchery and wild fish in the total sample using the CWT data. Each tag represents a particular lot of releases that have a specific tagging percentage. Using this tagging percentage, it is possible to estimate the expected percentage of hatchery fish from that lot in a sample. However, the small number of CWT fish captured and the large expansions required means that any estimates are approximate. The otolith and the CWT estimates of the percentage of hatchery fish follow similar trends (Table 4) except for the June sample. The high estimates of hatchery percentages using otoliths for the May (83.7%) and the July sample (73.4%) were the same samples that had high estimates of hatchery fish using CWT's i.e. May 74.9% and July 92.8%. Similarly, the estimate of hatchery fish was low in September for both methods. The otolith method estimates were higher than the CWT estimates for the older fish (April sample), but both methods appear to converge at estimates of approximately 50 to 65% hatchery fish.

We identified approximately a 10% error for the otolith method when hatchery fish were identified, i.e.10% of the hatchery were identified as wild. It is possible that the error for wild fish is different and a percentage higher than 10% of the wild fish were misidentified as hatchery fish. Thus, the estimate of hatchery fish could be high if more than 10% of the wild fish were identified as hatchery fish. CWT analysis has been the standard method of estimating the percentage of hatchery fish, but the CWT method obviously has inherent errors such as tag loss after the tagging procedure losses were determined and the non reporting of marks. Thus we concluded that the otolith daily increment method provided reliable estimates of relative abundance wild ocean, wild stream, and hatchery ocean life history and rearing types.

Changes in percentage of hatchery and wild juveniles

The percentages of ocean age 0 juvenile chinook of the various rearing types is shown in Table 3. There is a definite change in the trend in the percentages. Hatchery fish initially have a high percentage, but decline to a projected estimate of approximately 50% (Fig. 1). The trend in Fig. 1 is influenced by the September estimate that has an anomalously low percentage of hatchery fish. This occurred, apparently, because there was a large number of wild ocean smolts that entered the Strait of Georgia late in the downstream migration, possibly in late June and July. If the September estimate is omitted the projected percentage of hatchery fish is approximately 62% and 38% wild fish. The percentage of hatchery fish estimated in the April 21-27 sample of older fish was 67%, possibly indicating that the higher percentage of hatchery fish is more appropriate. The percentages of wild ocean and wild stream types varied considerably among the samples (Table 3) with a projected estimate of approximately 57% stream type and 43% ocean type. This estimate of 57% wild stream type is considerably higher than the 19% observed in the April 21-27 sample. The April sample is not an estimate from the same brood years, but may indicate that there is a migration of wild stream type fish out of the Strait of Georgia in the winter of their first ocean year. At this time we have not estimated the actual abundance of rearing types. It will be interesting to determine how these abundance's have changed with the addition of the hatchery reared ocean type fish.

Growth

The growth of the life history and rearing types was compared using linear regressions fit to lengths in each sample. Strait line fits were considered to be the most appropriate because of the high R^2 values (Fig. 2). As expected, stream-type smolts were larger than all other smolts when they first entered salt water (Fig. 2). Wild ocean type smolts were smaller than the average size of hatchery smolts, which were indistinguishable from the average size of all fish in each sampling period. The rate of growth (slopes) of hatchery fish and stream-type fish was virtually identical and significantly faster than wild ocean type fish (F test, $P < 0.05$). The rates of growth resulted in persistent length differences such that at the end of the year, stream type fish were larger than hatchery fish, which were larger than wild ocean type fish.

The use of length changes to estimate growth rates can be confounded by size selective mortality or movement. If size selective mortality or movement was affecting the relative size percentages from one sample to another, the selection would have to remove the equivalent percentage from each life history and rearing type, regardless of the absolute length within the length distribution for the size differences to persist. It is possible that the size differences among rearing and life history types eventually disappear because the April sample of fish older than ocean age 0 years did not show these differences (Table 5), but these fish are from different brood years.

The length distributions of the total catches (Fig. 3) tended to be skewed to the right except for the September length frequency distribution which was distinctly bimodal. The bimodal distribution occurred for both the hatchery and wild distributions. The wild distribution was a result of the two distinct distributions of the larger stream type and the smaller ocean type (Fig. 4). The hatchery length distributions were similar to other samples except in the range of 185 to 205 mm where there were low abundance's. By November, the lengths of hatchery fish did not show this pattern (Fig. 5). In November, the wild life history types still had distinct length frequency distributions (Fig. 5), but substantially more overlap of lengths than in the September sample.

An important conclusion from the growth observations was that the mean size differences of the life history and rearing types, persisted throughout the year. The rates of mean length increases were the same for hatchery fish and wild stream type fish, but both were faster than the wild ocean type increases If this is a valid and consistent observation, the explanation could be that the wild ocean type fish grow slower or that the larger fish of this life history type are selectively removed from the population. Another explanation may be the late migration of large numbers of wild ocean type fish into the ocean in late June or early July. The length frequency of the September sample clearly shows a distinct group of smaller wild ocean type juveniles, consistent with the reduction in the percentage of hatchery fish in the September sample as reported earlier. If the April sample of older fish is an indication of the size changes that will occur over the winter, both hatchery and wild ocean types will increase in mean size relative to the wild stream type. Because most of the marine mortality should have occurred, any size changes should result from either growth changes or size selective movements.

Gut analysis

The stomach contents of the small samples of chinook juveniles were examined in detail in the September 11-22 and November 6-18 cruises (Table 6). Using 10x magnification we identified contents either to species or as too digested to identify. In September, 71% of the fish had stomach contents and in November 60% had contents. Of the fish with contents that could be identified, common items included amphipods, fish, crab larvae, euphausiids, calanoid copepods, insects, shrimp, squid, and octopus. Using the percent frequency of occurrence (i.e., the percentage of fish with a particular food taxon in the stomach) the most common items were amphipods, crab larvae, euphausiids, and fish (Table 6). If the average weight of the contents were compared (Table 6) , the valve species were important items in the gut, but fish (mostly herring) became a more common item because of the larger individual weights. The three rearing and life history types ate similar organisms, but the wild ocean type appears to consume less fish. Unfortunately, the small sample analyzed in 1995 did not contain stream type fish. As more stomachs are analyzed we will be able to determine our preliminary results are valid and wild ocean type fish consume significantly less fish than the other types.

Distribution

In general, there were some differences ion distribution as the smolts moved into the ocean. In the May 23-30 sample, ocean age 0 juveniles were not found in the central strait. The areas of concentrations were immediately off shore from two major hatcheries and off the mouth of the Fraser River. Wild smolts were found only off the Fraser River, where slightly over one half (63%) were the wild stream type. By June 19-26, ocean age 0 juveniles were common in the central portion of the strait. By the end of the year there were some differences in relative abundance's, such as a tendency for wild fish to be in the south and hatchery fish in the north, but the various types were mixed throughout the strait in the April 1 sample (Table 7, 8).

Discussion

The otolith method that was used to identify the rearing types has been described previously Zhang et al. (1995), Beamish et al. (1995) and appears valid as indicated by the 90% accuracy in identifying CWT hatchery fish. The method also readily identifies wild stream type fish as these fish can be distinguished by a larger number of freshwater daily growth zones, a different pattern of growth of the increments and a fresh water annulus. There is still some difficulty identifying stream type hatchery fish, thus, a few of the wild stream type fish listed in this report would be hatchery fish, but the percentage will be small. If hatchery and wild smolts are about equal in abundance and the stream type and ocean type wild smolts are about equal in abundance, the less than 5% hatchery reared stream type fish would translate into about a 10% error in the estimate of the number of wild stream type. The error associated with classifying wild ocean fish in unknown. Here we assumed it would be equal to hatchery fish or 10%. However, if a higher percentage of wild fish were incorrectly identified as hatchery fish, our estimate of hatchery fish may be high. In this study the CWT estimates of the percentage of hatchery fish approximated the trends observed using the otolith estimates. In a previous study Zhang et al. (1995), the error associated with identifying wild fish was not found to differ from the error associated with hatchery fish. In general, the otolith method of identifying life history and rearing types appears quite convincing, thus we believe that our estimates of the various life history and rearing types are reliable. The fishing gear, also represents a new method of sampling chinook. Thus we believe we have been able to collect representative samples of the population.

In the past it was believed that wild ocean type chinook were the rearing type that remained in the strait as juveniles in their first ocean year and contributed heavily to the recreational and commercial fisheries (Healey 1980, Argue and Marshall 1976). In the 1960s, for example stream type chinook represented 3.4% of this catch (Healey 1983). Our study indicates that the hatchery-reared ocean type fish, now represent about 50-65% of the life history types by the end of the year. The remaining juveniles are a mixture of wild ocean and stream type. Relative to the wild ocean fish, wild stream type juveniles are more abundant late in the year than previously thought and there are clearly relatively fewer wild ocean types than in the past. There was a decline in the percentage of hatchery fish during the year but the reasons for the decline were not determined. One contributing factor may be the movement of wild, ocean type smolts into salt water, later in the year. Although we do not have abundance estimates, the number of wild ocean type smolts that enter the ocean late in the saltwater migration, appears to be quite large.

There was no apparent separation of the rearing and life history types in the strait after the first ocean year. The Strait of Georgia is a small coastal sea, and it would be unusual if there was evidence of separations in distributions. There is a possibility that diet differences exist, but the sample sizes are too small at this time to be certain that the differences in fish consumption are real.

The average size differences that existed when the smolts of the various rearing types entered salt water, persisted throughout the year. Even though from the April sample fish were from different brood years, the similarity in sizes may indicate that the size differences found in November do not persist longer than a year

In summary, we concluded that it was possible to study the biology and behaviour of the life history and rearing types using the otolith method. Using this technique, we observed a decline in the percentage of hatchery ocean type and an increase in wild types throughout the year so that by the end of the first ocean year, hatchery and wild fish were almost equally abundant as were wild ocean and wild stream type fish. Surprisingly, the size differences among these types persisted throughout the year. As the 1996 samples are collected and analyzed, it will be interesting to see how these life history and rearing types behave in their second ocean year.

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Table 1: Catches of chinook in the Strait of Georgia in 1995.

Date	Sample Type	Gear	Total Catch	Sample Lengths	Otolith Samples Analyzed
April 21-27	Older juveniles	Rope trawl[1]	251	251	251
May 23-30	Smolts	Beam trawl[2]	513	513	513
June 19-26	Ocean age 0, juveniles	Beam trawl[2]	361	361	361
July 6-21	Ocean age 0 juveniles and older juveniles	Beam trawl[3] and rope trawl[1]	841	841	271[5]
Sept. 11-22	Ocean age 0 juveniles and older juveniles	Beam trawl[2&3] and rope trawl[4]	378	378	378
Nov. 7-17	Ocean age 0 juveniles and older juveniles	Rope trawl[4]	302	302	302

[1]This rope trawl was slightly larger than the trawl used in September and November. [2]This is a smaller beam trawl than [3] and was fished from a smaller vessel than [3], [4]This is the smaller rope trawl described in this report. [5]When the otolith sample is smaller than the sample for lengths, the otolith sample was selected using random numbers.

Table 2. Estimated number of daily increments formed in freshwater.

Rearing Type	Average Numbers of Increments from Exogenous Feeding to Ocean Entry Number Examined)
Ocean-type hatchery	112±24 (150)
Ocean-type wild	89±33 (157)
Stream-type hatchery	205±21 (16)[1]
Stream-type wild	222±20 (22)

[1]This is a selected sample and not a random selection from all hatchery fish.

Table 3. Percentages of life and rearing types of ocean age 0 juveniles in the Strait of Georgia and the ocean age >0 years in April.

Date	Hatchery	Wild	Wild ocean	Wild stream
Ocean age <0 years				
May 23-30	82.8% (419)	16.4% (82)	36.6% (30)	63.4% (52)
June 19-25	61.3% (217)	38.7% (137)	63.5% (87)	36.5% (50)
July 6-19[1]	73.6% (192)	26.4% (69)	29% (20)	71% (49)
Sept. 11-22[1]	40.8% (135)	59.2% (196)	72.5% (142)	27.5% (54)
Nov. 7-17	63.2% (139)	36.8% (81)	33.3% (27)	66.7% (54)
Ocean age >0 years				
April 21-27	68.4% (145)	31.6% (67)	80.6% (54)	19.4% (13)

Table 4. Percentages of hatchery and wild ocean age 0 in the Strait of Georgia chinook using CWT analysis.

Date	Catch	Number of CWT Fish	Expand Numbers of Hatchery Fish	% Using CWT	% Using Otolith
May 23-30	512	25	384	75.0	83.7
June 19-25	361	9	139	38.6	61.3
July 6-19	692	41	642	92.8	73.4
Sept. 11-22	334	9	87	26.0	38.5
Nov. 6-18	225	11	82	36.4	63.9
Ocean age > 0					
April	251	10	119	54.1	68.4

Table 5. Average fork lengths (mm) of ocean age 1 and 2 years juveniles sampled from April 21-27, 1995.

	Ocean Age 1 mm (n)	Ocean Age 2 mm (n)
Hatchery	367.5 (35)	565.8 (19)
Wild Ocean	367.3 (9)	559.9 (11)
Wild Stream	360.5 (11)	(0)

Table 6. Frequency of occurrence of food items in ocean age o chinook stomachs, using the percentage of frequency, and the percentage weight (wt).

		Most occurring		2nd most occurring		3rd most occurring		
September 11-22								N
Wild Stream	%	Fish	53%	Amphipods	13%	Euphausiids	7%	15
	wt	Fish	76%	Amphipods	2%	Euphausiid	1%	
Wild Ocean	%	Euphausiids	32%	Amphipods	27%	Crab larvae	24%	41
	wt	Amphipods	20%	Euphausiids	16%	Crab larvae	13%	
Hatchery	%	Amphipods	38%	Crab larvae	27%	Fish	23%	60
	wt	Fish	50%	Amphipods	9%	Crab larvae	8%	
November 6-18								
Wild Ocean	%	Amphipods	38%	Crab larvae	27%	Euphausiid	27%	26
	wt	Amphipods	41%	Euphausiid	18%	Crab larvae	15%	
Hatchery	%	Amphipods	39%	Euphausiid	26%	Fish	23%	69
	wt	Fish	75%	Amphipods	8%	Shrimp	7%	

Table 7. Distribution of the rearing types of ocean age 0 fish in November and older than ocean age 0 in April. Catches are the number of fish per 1 hr. set.

Area	Hatchery (n)	Wild Ocean (n)	Wild Stream (n)
November 7-17			
North	4 (46)	0.8 (6)	0.3 (2)
South	2.2 (93)	1.7 (75)	1.2 (52)
April 21-27			
North	5.3 (111)	1.9 (33)	0.5 (9)
South	3.1 (34)	1.4 (21)	0.3 (4)

Table 8. Depth distributions of the rearing and life history types. Catches are number of fish per hour for the rope trawl for the September and November samples.

Depth	Total (n)	Hatchery	Wild	Wild-ocean	Wild-stream
September 11-22					
0-20	23.1 (127)	7.3 (40)	15.8 (87)	12.7 (70)	3.1 (17)
21-40	9.5 (19)	2.5 (5)	7.0 (14)	5.0 (10)	2.0 (4)
41-60	30.0 (40)	7.5 (10)	22.5 (30)	0	22.5 (30)
November 7-17					
0-20	6.8 (193)	4.3 (123)	2.5 (70)	0.7 (20)	1.8 (50)
21-40	7.1 (25)	4.0 (14)	3.1 (11)	2.0 (7)	1.1 (4)
41-60	1.0 (2)	1.0 (2)	0	0	0

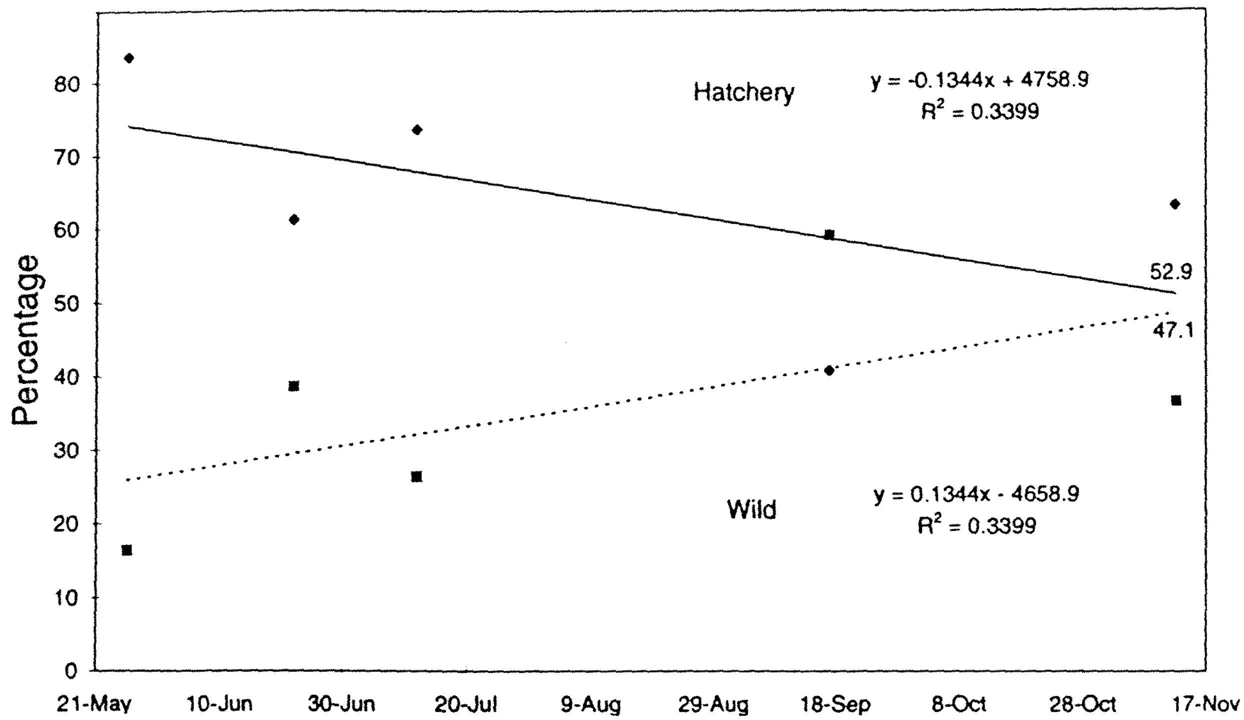

Fig. 1. Percentages of hatchery (solid line, solid diamonds) and wild (dotted line, solid squares) chinook, showing the decline in hatchery fish and the increase in wild fish towards the end of the year.

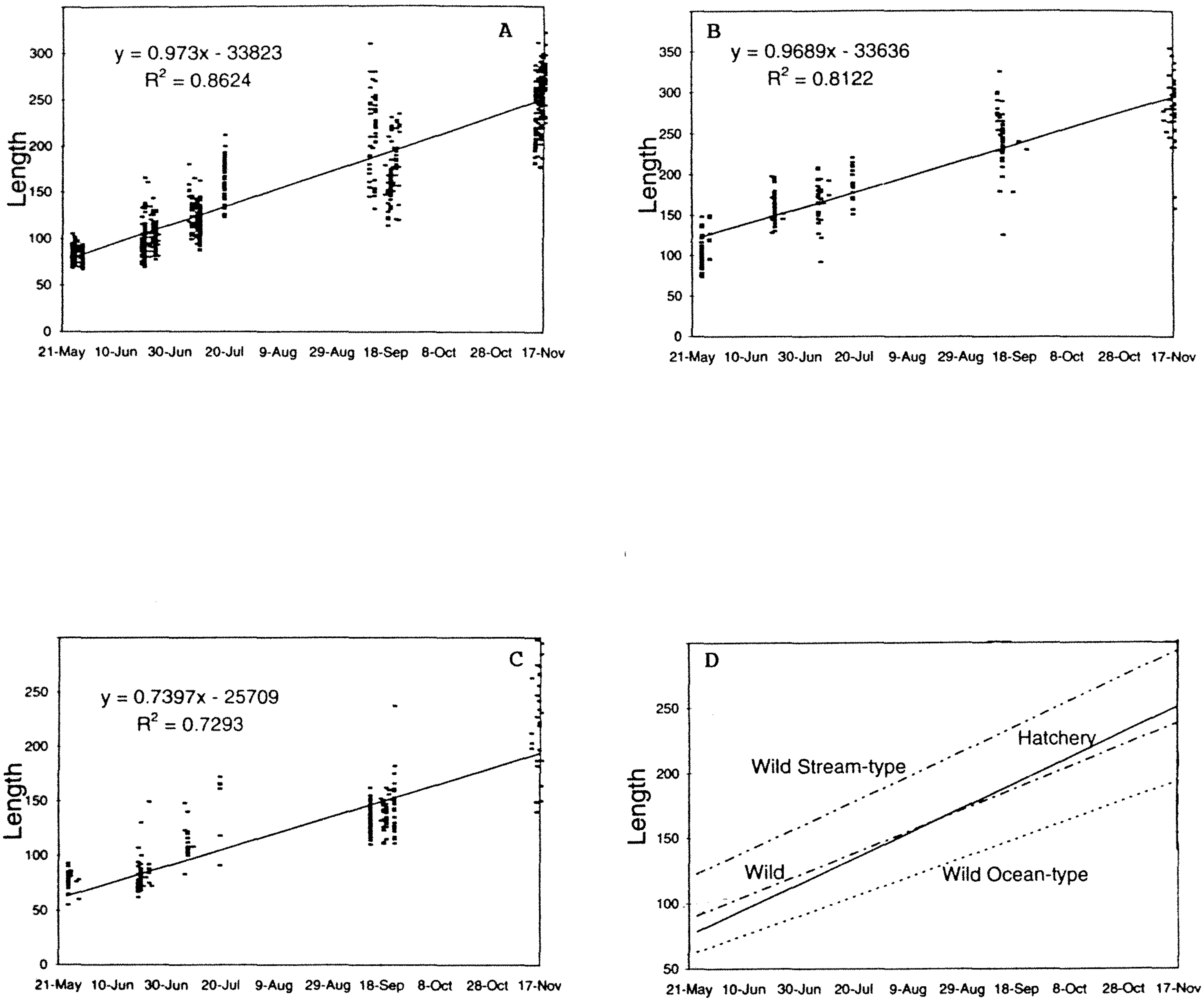

Fig. 2. Fork length (mm) changes in the samples of: (A) hatchery, (B) wild stream type, (C) wild ocean type, and (D) combined regressions, including a combined wild ocean and wild stream type.

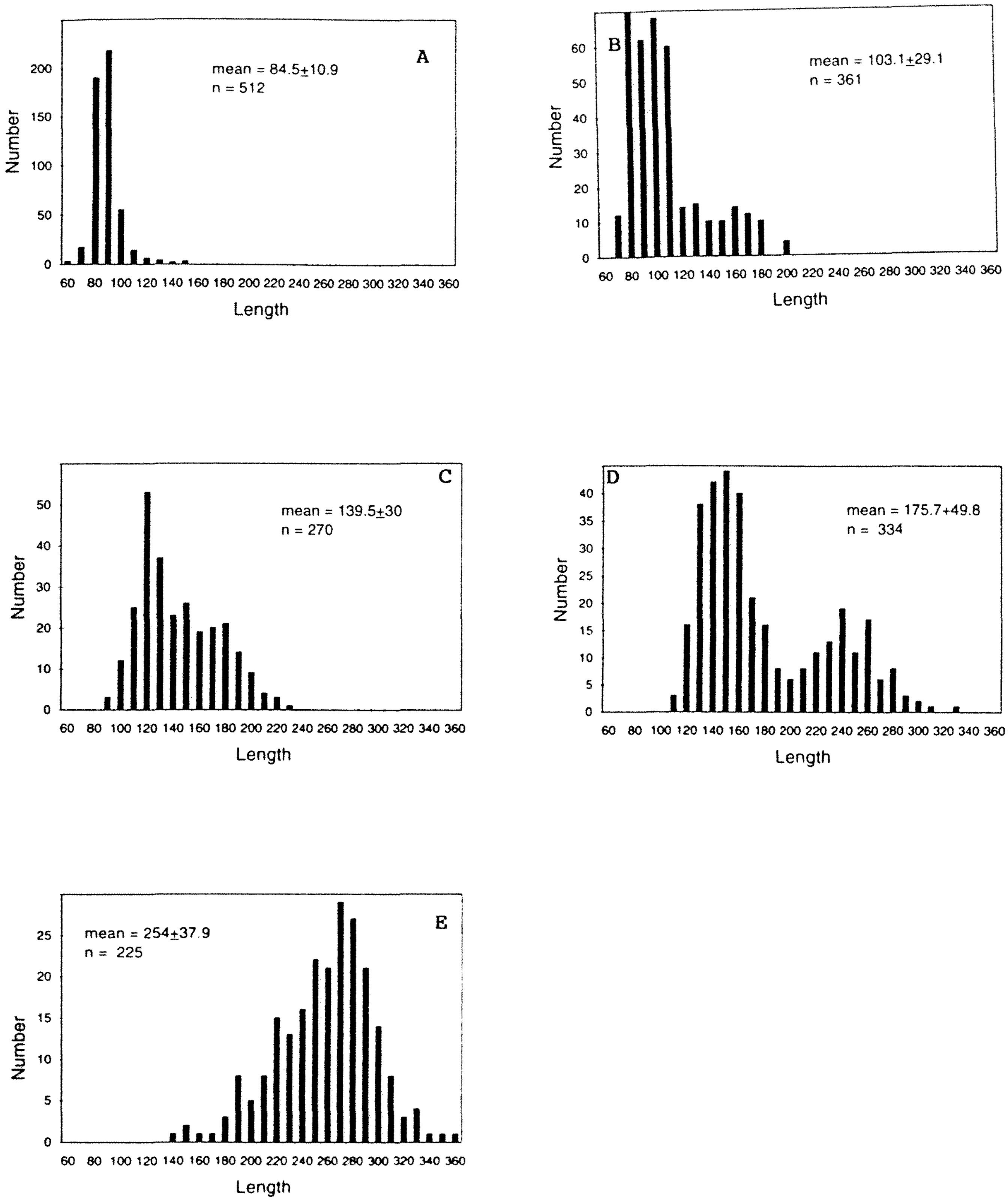

Fig. 3. Length (mm) frequency of catches of all rearing types for (A) May 23-30, (B) June 19-26, (C) July 6-21, (D) September 11-22, (E) November 7-17.

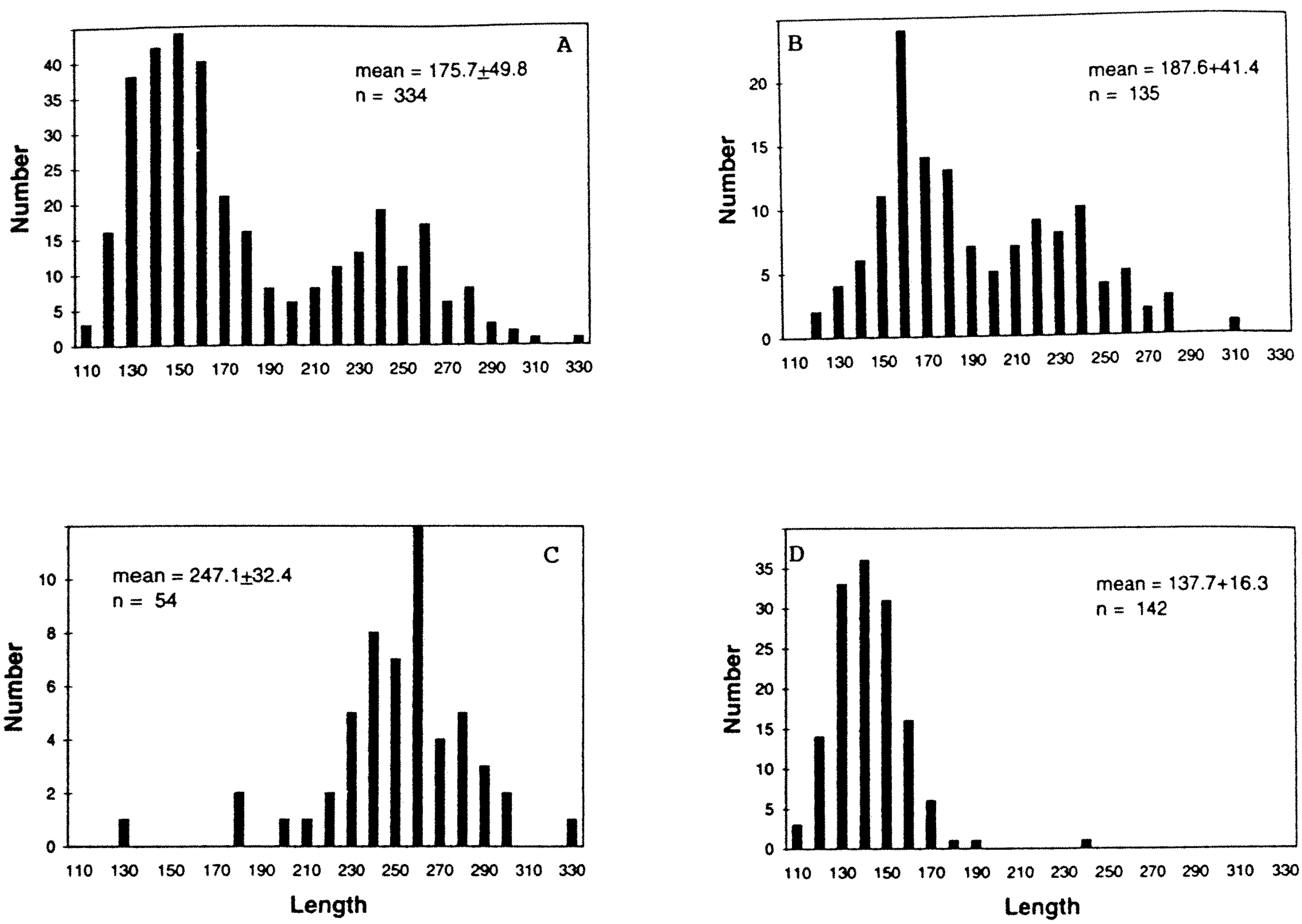

Fig. 4. Length (mm) frequency of September 11-22 catches of (A) all rearing types, (B) hatchery, (C) stream type, and (D) ocean type.

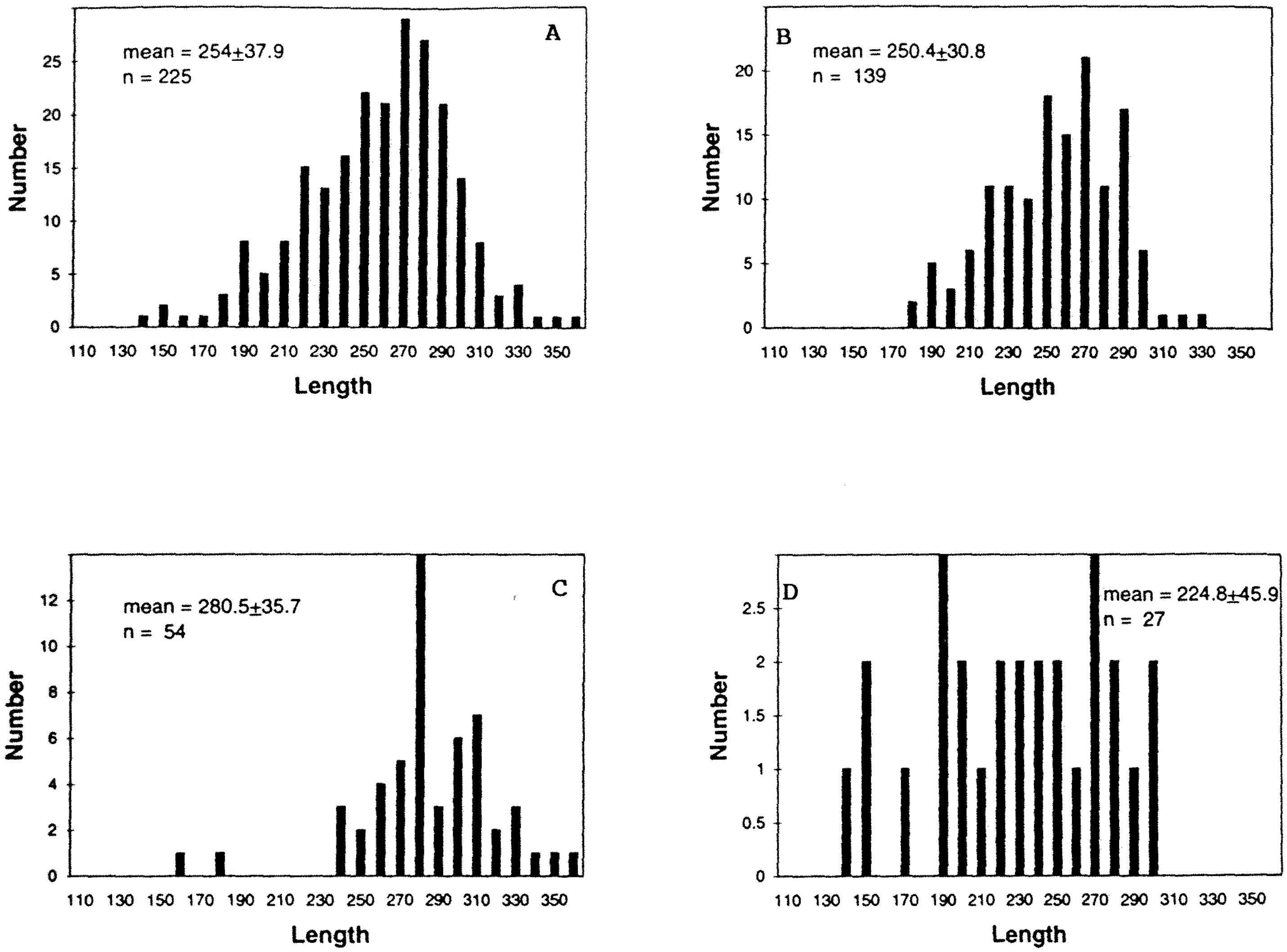

Fig. 5. Length (mm) frequency of November 7-17 catches of (A) all rearing types, (B) hatchery, (C) stream type, (D) ocean type.