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EFFECTS OF ENVIRONMENT AND HEREDITY ON GROWTH OF THE SOFT CLAM (*Mya arenaria*)

By HARLAN S. SPEAR and JOHN B. GLUDE

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ABSTRACT

Soft clams in the center of Sagadahoc Bay, Maine, reach an average length of 68 mm. in 5 years. Soft clams in another part of Sagadahoc Bay, Bedroom Cove, reach a length of only 49 mm. in 5 years. The reasons for the difference in growth rates in the two parts of this bay must be known for the management of the resource. This experiment was directed at determining whether the difference is caused by heredity or by environment.

Experimental areas were established in Bedroom Cove and in the center of Sagadahoc Bay. In each location, native clams and clams from the other area were planted. For further comparison, clams from two other flats were planted in each location. Growth rates were compared over a period of 1 year.

Native clams planted in Bedroom Cove grew 3.55 mm. in length during the year; clams transplanted from the other areas grew at a similar rate. Native clams planted in the center of Sagadahoc Bay grew 14.48 mm.; clams transplanted from the other areas grew at a similar rate.

Additional experiments were conducted at two other areas in Maine and at one area in Massachusetts. Results were similar to those of the Sagadahoc Bay and Bedroom Cove experiments.

The experiments demonstrated that environment, not heredity, is the important factor in growth. Clams from one origin may have highly significant differences in growth rate when planted in different areas. Clams of different origins assume similar growth rates when transplanted to the same area.

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EFFECTS OF ENVIRONMENT AND HEREDITY ON GROWTH OF THE SOFT CLAM (*Mya arenaria*)

By Harlan S. Spear and John B. Glude, *Fishery Research Biologists*

The relation of the soft, or soft-shell, clam (*Mya arenaria*) to its environment is such that some flats are favorable for seed-clam production and are not favorable for growth, while the reverse is true of other flats. This situation has resulted in the practice of transplanting clams from "seed" areas to "growth" areas, in order to take full advantage of both environments. Obviously it is desirable to know the relative effects of heredity and environment on the growth of the clams; if heredity has the greatest influence it would be desirable to select clams for transplanting from fast-growing stocks, whereas if environment is the dominant factor any convenient source of seed may be used with equal success. The relative effects of stock origin and growth environment, on clam growth, therefore constitute a subject of commercial importance as well as a subject bearing on the biological problem of heredity versus environment, or "nature versus nurture."

The growth rate of the soft clam varies along the New England coast (Turner 1948); in general, growth is slower in the more northerly and colder areas. In addition, there are local variations in growth rate not obviously caused by water temperatures. The experiment described here was designed to provide information on the relative effects of heredity and environment on the growth rate of soft clams.

Assistance in the field work of this experiment was provided by Richard E. Tiller, formerly of the Fish and Wildlife Service, and by Dana Wallace and John Hurst, of the Maine Department of Sea and Shore Fisheries, which cooperated in the experiment. David W. Calhoun, formerly of the Fish and Wildlife Service, assisted in the statistical analyses.

The Clam Investigations staff of the U. S. Fish and Wildlife Service has been studying the productivity of Sagadahoc Bay on Georgetown Island, Maine, in terms of the numbers of clams that can be removed annually without causing depletion. The annual clam census, conducted as a part of these studies, has shown that clams in the main part of Sagadahoc Bay grow much faster than those in Bedroom Cove, an adjacent part of the bay (fig. 1). Figure 2 shows comparative growth rates for the main part of Sagadahoc Bay and for Bedroom Cove, as determined by interpretation of rings on the shells.[1]

The reason for the difference in growth rates of clams in the two parts of Sagadahoc Bay must be known for efficient management of the resource. One possible reason is heredity, that is, that the clams in Bedroom Cove are a slow-growing race while those in the center of Sagadahoc Bay are a fast-growing race. Another possible reason is that a combination of factors makes the environment in the center of the bay conducive to rapid growth, whereas the environment in Bedroom Cove permits only slow growth. If growth rates differ because of heredity, a management plan to increase production might include replacing the slow-growing stock with fast-growing clams; if differences in growth rates are due to environment, the best management plan might be to harvest the clams from Bedroom Cove at a smaller size than those in the center of the bay, or to transplant them to areas where they would grow faster.

Several researchers have discussed the causes of variations in the growth rate of soft clams. Mead (1900) observed that clam growth depended directly upon the supply of microscopic organisms in the water. Kellogg (1905) indicated that clam growth depended on the amount of available food

[1] Spear, Harlan S., 1954. Results of population census, Sagadahoc Bay, Maine. Unpublished report on file at U. S. Fishery Laboratory, Boothbay Harbor, Maine.

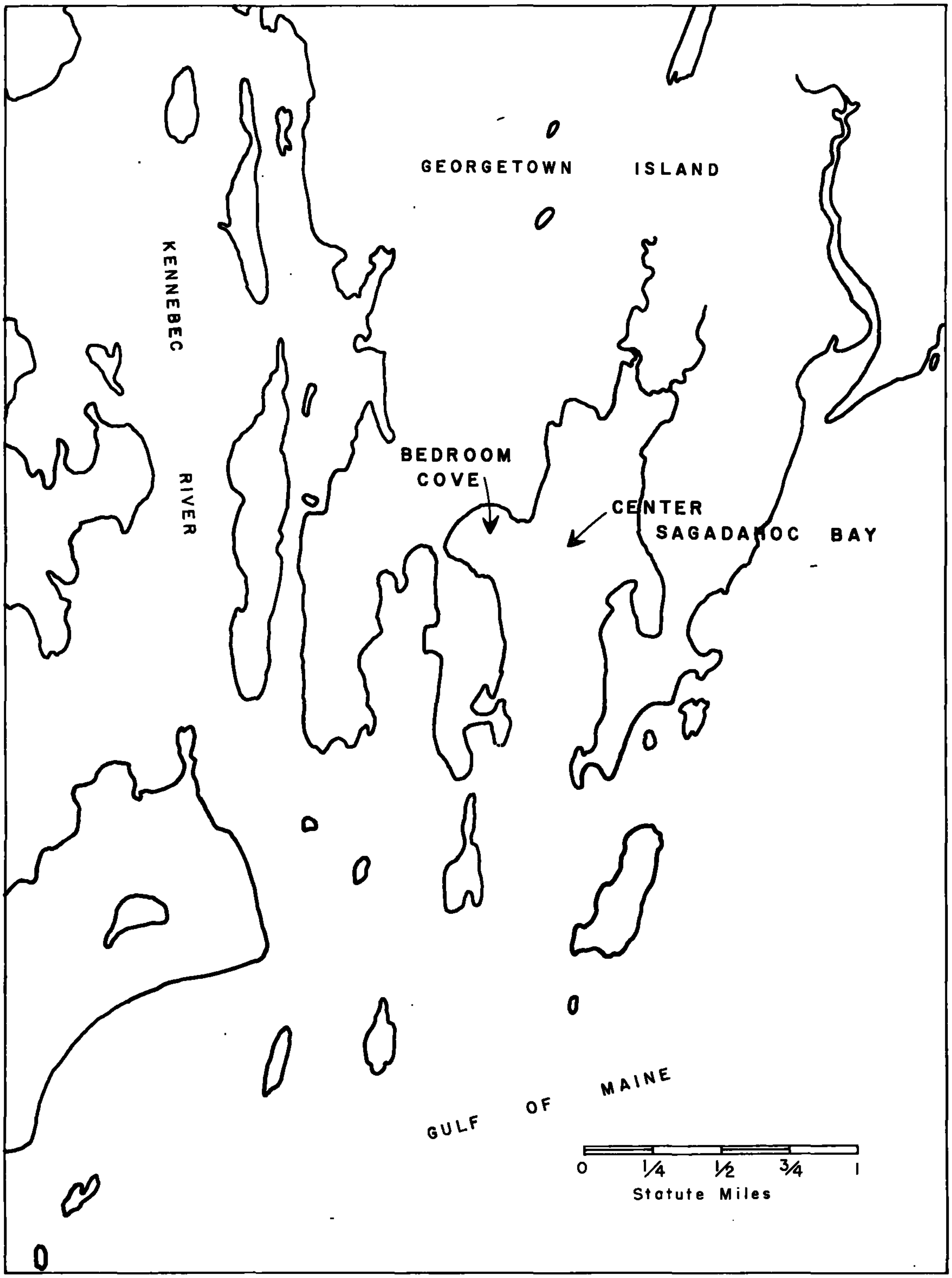

FIGURE 1.—Sagadahoc Bay, Georgetown Island, Maine.

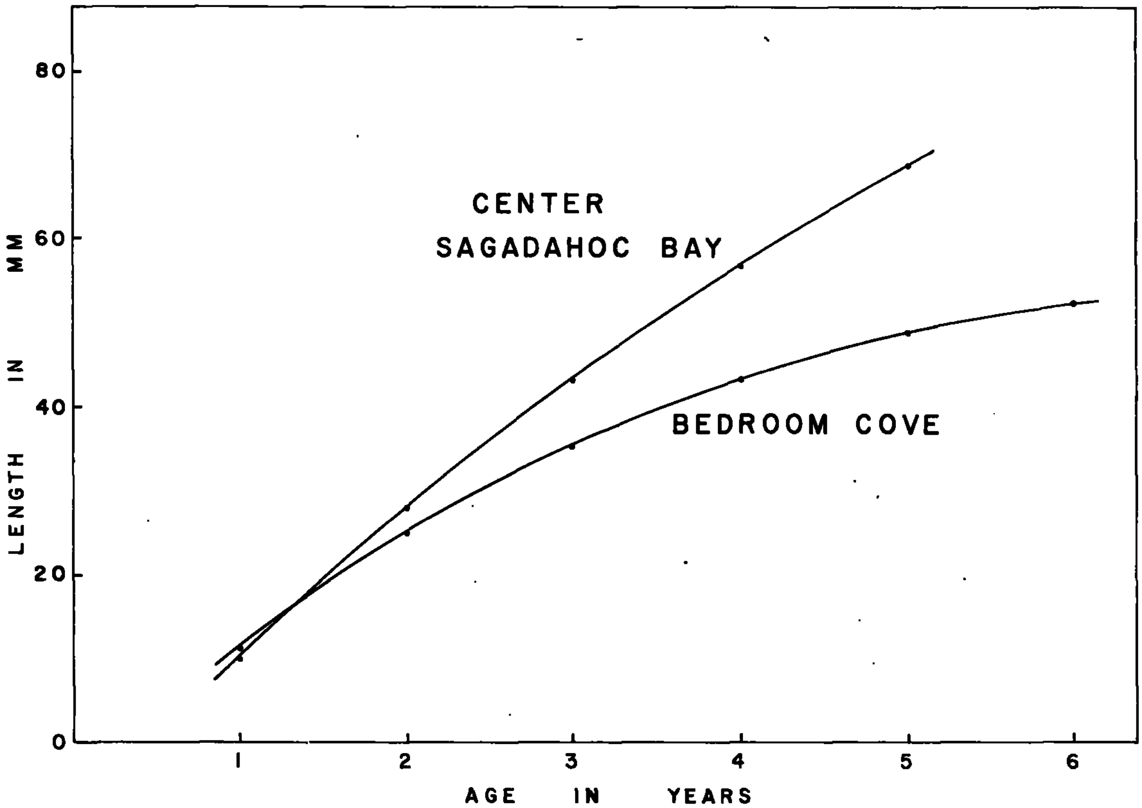

FIGURE 2.—Comparative growth rates of soft clams from center of Sagadahoc Bay and from Bedroom Cove.

and that growth is accelerated where currents are swift. Belding (1930) reported that the most important factor in clam growth is a good current, in its role as a food carrier, oxygen bearer, lime furnisher, and sanitary agent. Newcombe (1935) showed that seasonal growth rates for clams during the same year and during different years correspond with abundance of diatoms and not with temperature. He also stated that excess surface silt on the beach limits the growth rate and survival of *Mya arenaria*.

Each of the authors cited attributes variations in growth rate to one or more environmental factors. The possibility that growth variations are indications of hereditary racial differences needed to be explored.

DESIGN OF EXPERIMENT

The experiment was based on the hypothesis that if growth variations are due to hereditary factors, transplanted clams should maintain the growth rate they had in their native habitat, whereas if environment is the cause of growth variations, transplanted clams should assume the growth characteristics of native clams in the new area. Clams were transplanted into various areas, and the growth rates were measured in terms of increase in shell length during the experimental period of 1 year.

Experimental areas were established in Bedroom Cove and in the center of Sagadahoc Bay (fig. 1). In each area we planted native clams and clams from the other area. For a further comparison we planted in each area clams from two other flats, Western Beach and Meetinghouse Cove (fig. 3). Western Beach is a sandy flat at the mouth of the Scarboro River where seed clams are abundant; the growth rate of clams at Western Beach is intermediate between that in Sagadahoc Bay and that in Bedroom Cove. Meetinghouse Cove is a silty area in the Medomak River system; seed clams are extremely abundant there and the growth rate is low, but better than in Bedroom Cove.

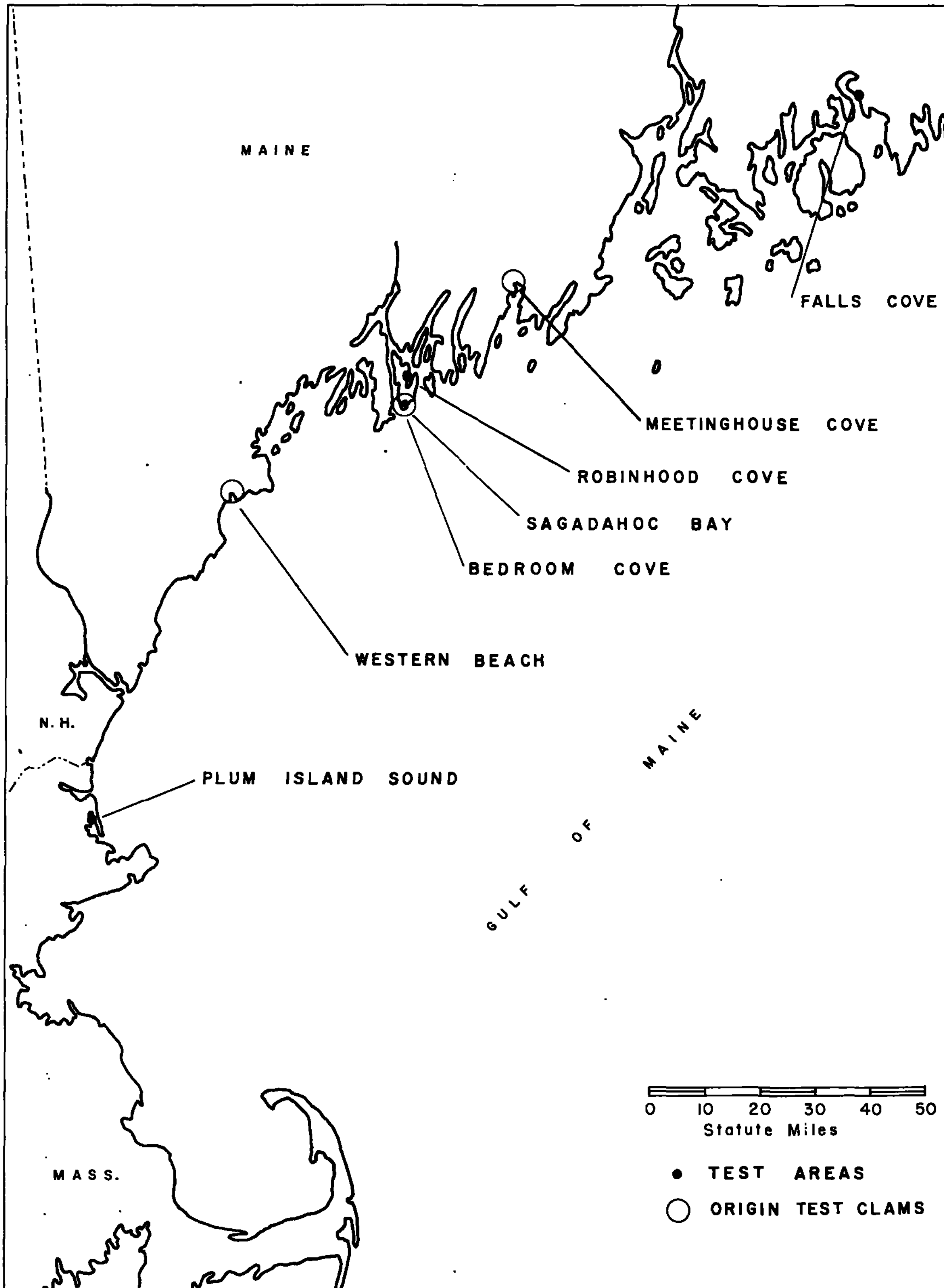

FIGURE 3.—Location of test areas and origin of test clams along the New England coast.

TABLE 1.—*Average growth of clams in test areas*

[Values based on samples taken November 1951 to March 1952]

Tested in—	Soil type	Transplanted from—	Soil type	Date planted	Initial length	Mean growth	Proportion recovered after 1951 growing season
				1951	*Mm.*	*Mm.*	*Percent*
Bedroom Cove	Sandy silt	Western Beach	Sand	Feb. 28	26.9	3.99	56.0
		Meetinghouse Cove	Silt	Mar. 1	27.5	6.18	50.7
		Sagadahoc Bay	Sand	Mar. 1	33.7	2.42	56.7
		Bedroom Cove	Sandy silt	Mar. 1	29.3	3.55	50.0
Sagadahoc Bay	Sand	Western Beach	Sand	Feb. 28	26.6	17.09	38.7
		Meetinghouse Cove	Silt	Mar. 2	27.8	20.30	24.7
		Sagadahoc Bay	Sand	Mar. 2	32.2	14.48	67.3
		Bedroom Cove	Sandy silt	Mar. 2	28.9	18.36	40.7
Robinhood Cove	Silt	Western Beach	Sand	Mar. 7	33.4	14.69	3.2
		Meetinghouse Cove	Silt	Mar. 7	28.9	18.03	7.6
		Sagadahoc Bay	Sand	Mar. 7	36.1	11.74	5.4
		Bedroom Cove	Sandy silt	Mar. 7	32.0	16.21	5.6
Falls Cove	Gravelly silt	Western Beach	Sand	Apr. 2	25.0	2.26	31.3
		Meetinghouse Cove	Silt	Apr. 2	26.8	3.87	66.7
		Falls Cove	Gravelly silt	Apr. 2	21.3	2.85	6.5
Plum Island Sound	Sandy silt	Western Beach	Sand	Apr. 5	26.0	[1] 19.03	0
		Meetinghouse Cove	Silt	Apr. 5	25.6	[1] 19.14	0
		Plum Island Sound	Sandy silt	Apr. 5	35.0	[1] 19.69	0

[1] Growth at Plum Island Sound is based on shell readings of clams that were dead at time of recovery.

To increase the geographical scope of the experiment, additional experimental plots were established in Robinhood Cove and Falls Cove in Maine, and in Plum Island Sound in Massachusetts (fig. 3). The design of the experiment is summarized in table 1.

EXPERIMENTAL PROCEDURE

Soft clams with an approximate length of 25 mm. were used in the experiment. This initial length was chosen because clams near this size were available in all areas and because (the growth rate of small clams being rapid) differences between areas or plots would be greater than if large clams had been used. Another reason for choosing clams about 25 mm. long was that growth rates would be comparable with those listed by Belding (1930).

Each clam was marked with Volger's opaque ink to ensure identification of origin. Previous experiments have shown that this ink remains visible on transplanted clams for a period of 2 to 4 years. Origins were designated by symbols in red or black ink so placed as to cover check marks on the shells that might later be confused with the planting check. Care was taken to avoid injury from contact of the ink with the mantle or other soft parts.

Clams from each origin were planted in a separate row containing 13 plots spaced 1 yard apart. Twelve of these plots were 1 square foot in area and contained 50 clams each, for monthly samples. The thirteenth plot in each row was approximately 4 square feet in area and contained a reserve supply of about 200 clams. The rows were parallel, 1 yard apart, and so located that all plots were at the same tidal level and were exposed to the same tidal current. All clams were carefully inserted part way into the substrata to prevent them from being washed away before they became established in the sediment. In discussion of the experiment, each row containing clams from a single origin is termed a "group".

One plot from each row in Sagadahoc Bay and in Bedroom Cove was dug each month during 1 year. The high mortality of test clams in the other experimental locations prevented adequate sampling during the entire year, but monthly samples were taken as long as survival permitted.

At the time of recovery, all clams were measured to the nearest millimeter with vernier calipers for planted length and total length. The planted length was determined by measuring the length of clams at the check mark on the shell caused by transplanting. Mean growth for each plot was computed from the planted and total lengths. Summaries of growth, by months, in the five test areas are given in appendix A; the mean growth for each area, based on selected samples, is shown in table 2.

TABLE 2.—*Mean growth of clams in five test areas, based on selected samples*

Test area	Mean growth	Number of clams on which mean growth is based
	Mm.	
Bedroom Cove	3.99	320
Sagadahoc Bay	16.84	276
Robinhood Cove	15.49	109
Falls Cove	3.28	160
Plum Island Sound	19.35	321

ANALYSIS OF RESULTS

SURVIVAL

Survival of planted clams at Bedroom Cove and Sagadahoc Bay was high enough that sufficient clams remained after the 1951 growing season to provide reliable growth data. The proportion recovered from plots dug in December 1951 and in January, February, and March, 1952, ranged from 24.7 to 67.3 percent, as shown in table 1. The survival at Robinhood Cove was very poor; only 3.2 to 7.6 percent of the planted clams were recovered after the 1951 growing season. Green crabs, *Carcinides maenas*, which are serious predators of clams, were very abundant in Robinhood Cove and are believed to have been responsible for the poor survival of planted clams. It was necessary to use clams from the supplementary plots to provide enough measurements for analysis of the growth.

Clams from Meetinghouse Cove survived satisfactorily when planted at Falls Cove, as indicated by a recovery of 66.7 percent after the 1951 growing season. Of the Western Beach clams planted at Falls Cove, 31.3 percent were recovered during the winter of 1951 and 1952, but survival of native Falls Cove clams replanted in the experimental area was extremely poor. On November 16, 1951, all of the monthly plots and the supplementary plot were dug, and only 13 live clams were recovered. The poor survival of Falls Cove clams is believed due to their small size, which made them more susceptible to injury from the marking ink used on their shells. If Volger's opaque ink touches the mantle or siphon of the clam it will injure the tissues. Since these clams were smaller than those in any other group, the chances of injury from this source were greater. The growth of Falls Cove clams that survived was intermediate between that of the Western Beach clams and that of the Meetinghouse Cove clams planted at Falls Cove, which had a much higher rate of survival. If the marking ink was the cause of the mortality, it appears that it did not affect the growth rate of the clams that survived.

It is likely that the initial size of 21.3 mm. given in table 1 for native clams replanted at Falls Cove is somewhat high because it is based on shell measurements of the 13 clams recovered at the end of the experiment. Many of the clams planted in the spring of 1951 were 12 to 16 mm. long and had the thin shells characteristic of clams of this size. It therefore appears likely that the marking ink was the cause of the poor survival. It was unfortunate that clams closer to the desired planted size of 25 mm. were not available at this location.

Each group of clams planted at Plum Island Sound had a mortality of 100 percent during the late summer and autumn of 1951. Before this time, however, these clams had grown at an extremely rapid rate, as shown in table 1. If we can assume that there was no differential mortality among the three groups, the measurement of growth from the shells of dead clams can be used in the analysis. Since the total mortalities of the three groups were identical and since growth rates were nearly identical, varying only from 19.03 to 19.69 mm., it is likely that inclusion of these data will not cause any significant error in the analysis. In fact, the conclusions are the same whether or not this group is included in the analysis.

The percentage recovery after the 1951 growing season shown in table 1 is a rough indication of survival, and is based on the number of clams dug from plots during the winter of 1951–52. It is not a true measure of survival, since it does not take into account the clams that moved, or were moved by hydrographic forces, away from the planting location. Frequently, clams planted in one row were recovered in other rows. Sample digging in the vicinity of the test plots also showed that the marked clams had spread over a considerable area. Therefore, the percentage recovery listed in table 1 might be considered as a minimum percentage survival.

INITIAL SIZE

All clams obtained from each source for use in this experiment were dug at the same time and had a common mean length, regardless of the area to which they were transplanted. At the time of recovery, however, the initial length, based on measurement of the check-mark on the shells caused by the transplanting, varied among test areas. In each case, the clams recovered from plantings at Robinhood Cove had a greater initial length than those from corresponding groups in the other test areas. It is likely that the smaller clams planted at Robinhood Cove were eaten by green crabs (these smaller clams were nearer the surface of the flats), which resulted in a greater initial length of clams recovered in this area.

GROWTH

Mean growth shown in table 1 is based on the difference between total length and initial, or "planted," length of each clam as determined at the time of recovery. Monthly samples taken during the winter of 1951–52 were combined to provide an adequate sample for statistical analysis. Combining these samples was justified by the fact that there is virtually no growth during this period, as shown by figures 4 and 5.

The mean growth rates of test clams ranged from 2.26 mm. for a group at Falls Cove to 20.30 mm. for a group at Sagadahoc Bay. Table 1 and figures 4 and 5 show that there is a tendency for growth rates to vary less within each test area than between test areas. At Bedroom Cove the native clams grew only 3.55 mm., but clams transplanted from three other origins also grew slowly. At Sagadahoc Bay the clams from the same origins as those planted at Bedroom Cove grew several times as much. At Robinhood Cove all groups grew much faster than did those at Bedroom Cove. Native clams at Falls Cove averaged only 2.85 mm. growth, and those transplanted from Meetinghouse Cove and Western Beach also grew very slowly. Contrast this with Plum Island Sound, where clams from Meetinghouse Cove and Western Beach grew more than 19 mm.

Statistical analyses (described in appendix B) show that the differences in mean growth between test areas are highly significant. It is safe to conclude that clams from a common origin adopt

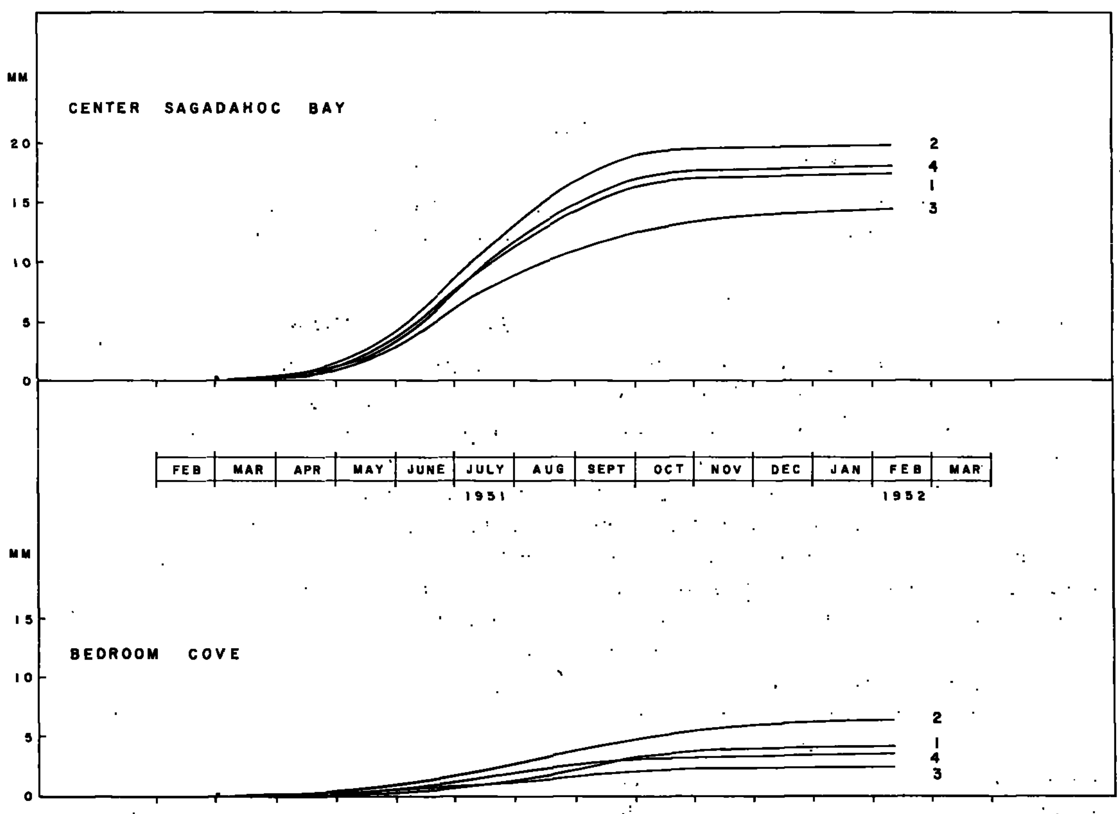

FIGURE 4.—Growth curves for groups of clams planted in Sagadahoc Bay and in Bedroom Cove, smoothed by moving averages of three. Origin of clams was as follows: 1, Western Beach; 2, Meetinghouse Cove; 3, Sagadahoc Bay; 4, Bedroom Cove.

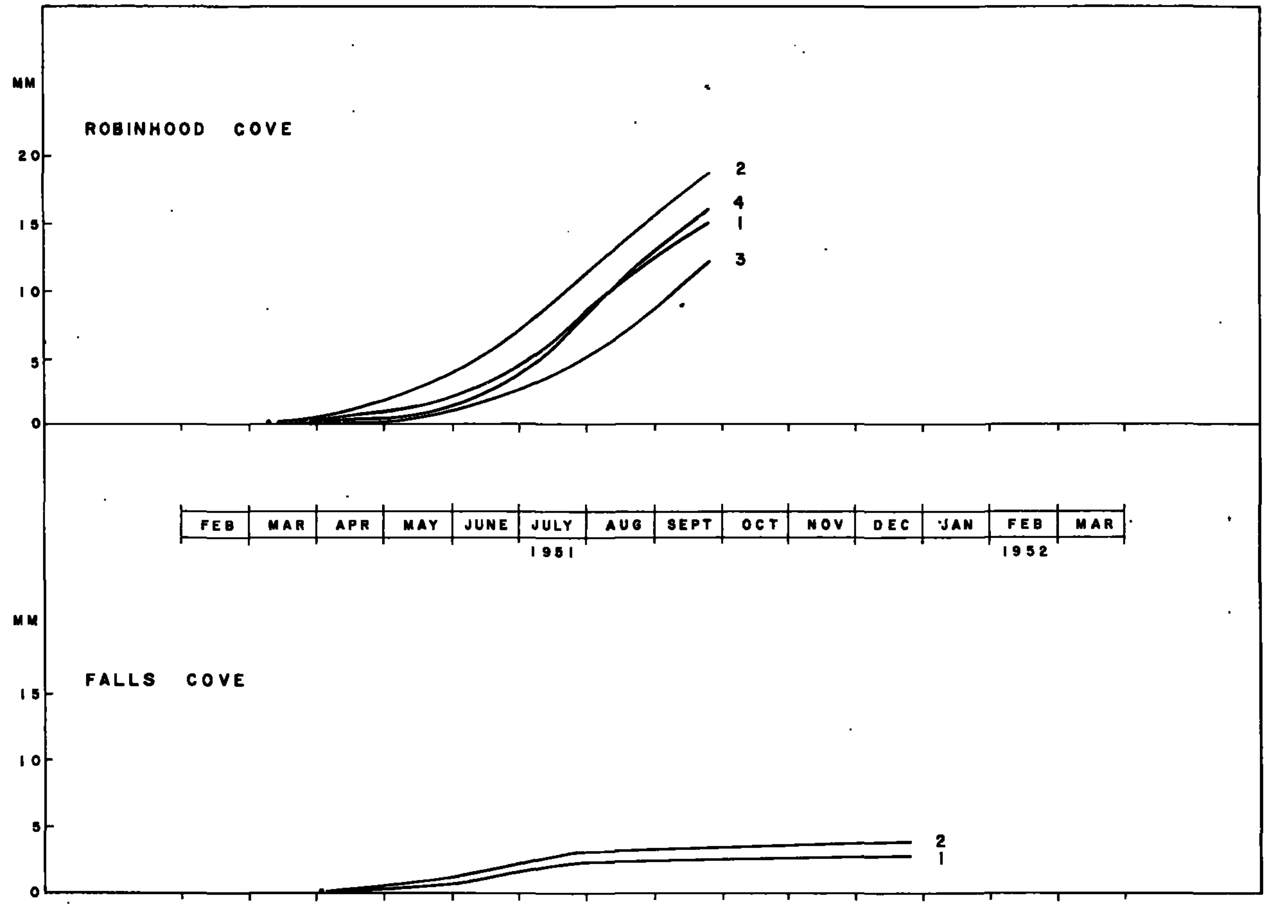

FIGURE 5.—Growth curves for groups of clams planted in Robinhood Cove and in Falls Cove, smoothed by moving averages of three. Origin of clams was as follows: 1, Western Beach; 2, Meetinghouse Cove; 3, Sagadahoc Bay; 4, Bedroom Cove.

significantly different growth rates when transplanted to areas of different growth conditions.

The importance of environment as opposed to heredity in affecting the growth rate of clams is emphasized by these results. If heredity were the cause of the differences in growth rates in various areas, we should expect clams that grew fast in their native beds to continue to grow fast when transplanted. Likewise, slow-growing clams would be expected to continue their slow rate of growth after transplanting. Instead, the growth rates of clams in this experiment varied with new environments. For example, Bedroom Cove clams, which grew only 3.55 mm. in their native environment, grew 18.36 mm. in Sagadahoc Bay. At the same time, Sagadahoc Bay clams, which grew 14.48 mm. in their native area, grew only 2.42 mm. when transplanted to Bedroom Cove.

EFFECT OF ORIGINS ON GROWTH RATES

Analysis of variance tests by areas (see appendix B, table B–2) also show that there are significant differences in the mean growth of groups of clams within each test area. This result might be expected because of the spread in the growth curves (figs. 4 and 5). The growth curves for clams from Meetinghouse Cove were higher than for other groups in each of the four test areas where these clams were planted. The analysis of variance summarized in appendix B, table B–3, shows that the F value was reduced from 13.0 to 6.0 by omitting clams from Meetinghouse Cove. It is also apparent that Sagadahoc Bay clams contributed greatly to the differences within each test area because their growth rate was consistently lower than that of the other groups.

Since clams from Meetinghouse Cove appeared to have grown faster than any other group in each test area except Plum Island Sound, the differences in mean growth were analyzed by origins instead of by test areas. Differences between mean growth of groups of clams from different origins were not statistically significant, as shown by table B–4 in appendix B.

Although not statistically significant, the apparently faster growth of Meetinghouse Cove clams in four test areas suggests another factor in the experiment. Clams in Meetinghouse Cove have a history of slow growth. If this were a hereditary or racial characteristic, we should expect them to grow slowly after being transplanted to other areas. Instead, the growth rate of Meetinghouse Cove clams was numerically greater than that of clams transplanted from other origins.

On the other hand, native clams in the center of Sagadahoc Bay have a record of fast growth (fig. 2), as indicated by a growth of 14.48 mm. during the present experiment (table 1). In the three test areas where these clams were planted, however, their growth was numerically, although not statistically, less than that of any other group. As far as heredity is concerned, these clams would be expected to have grown fast after transplanting. Since they grew slowly, it is likely that a factor other than heredity was responsible.

EFFECT OF PREVIOUS ENVIRONMENT

A possible explanation for the fast growth of Meetinghouse Cove clams and the slow growth of Sagadahoc Bay clams after transplanting is the effect of their previous environment. Meetinghouse Cove is a shallow, silty cove on the west side of the Medomak River estuary. Tidal currents are slow, and this area is protected from current-inducing winds by the surrounding hills. There is a high concentration of slow-growing clams in this area, and competition for food must be extreme.

Sagadahoc Bay is a wide, sandy area exposed to the south winds. Both tidal and wind-induced currents are strong. The clam population consists of a few well-scattered, fast-growing individuals. Competition for food is not likely to be a factor influencing growth in this area.

Perhaps competition for food causes clams in Meetinghouse Cove to feed more actively or efficiently than those in Sagadahoc Bay which have an abundance of food. If this characteristic persisted after the clams were transplanted to new areas, the Meetinghouse Cove clams might be expected to grow faster and the Sagadahoc Bay clams slower, as was observed in the experiment.

SUMMARY

1. The objective of the experiment was to determine whether differences in growth rates of soft clams in two parts of one bay (Sagadahoc Bay) were caused by environment or by heredity. This determination is an economically important consideration in clam transplantation.

2. Test areas were established at five locations along the coast of New England, including the two parts of Sagadahoc Bay. Native clams and clams from two to four other sources were planted in each location.

3. Growth during one growing season was measured by monthly sampling.

4. Good survival resulted at Sagadahoc Bay and Bedroom Cove and in two of the three groups planted at Falls Cove. Survival was poor at Robinhood Cove because of depredation by the green crab, *Carcinides maenas*. For unknown reasons clams died in Plum Island Sound during the late summer.

5. Mean growth for clams in each test area was as follows: Bedroom Cove, 3.99 mm.; Sagadahoc Bay, 16.84 mm.; Robinhood Cove, 15.49 mm.; Falls Cove, 3.28 mm.; Plum Island Sound, 19.35 mm.

6. Differences between mean growths in the five test areas were highly significant, as shown by analysis of variance. Clams from a single origin grow at significantly different rates when transplanted to different environments.

7. Differences between growth rates of groups of clams from different origins within each test area were not statistically significant. Therefore, clams from different origins assume similar growth rates when transplanted to a single environment.

8. Although not statistically significant, the numerically faster growth of Meetinghouse Cove clams, and the slower growth of Sagadahoc Bay clams in all cases except one, suggest another factor influencing growth. A tentative explanation is the effect of previous environment, which caused clams from a slow-growing area (Meetinghouse Cove) to grow fast, and clams from a fast-growing area to grow slowly after transplanting.

Because the observed growth pattern was the opposite from that which would have been expected if heredity were the principal factor determining growth, the conclusions of the experiment are not altered.

9. The experiment demonstrated that environment, not heredity, was the important factor in determining growth of the soft clam.

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APPENDIX A—ORIGINAL DATA

NUMBER RECOVERED AND AVERAGE GROWTH, BY MONTHS, OF CLAMS TRANSPLANTED IN FIVE TEST AREAS

TABLE A-1.—*Bedroom Cove test area*

[Samples collected on dates marked by asterisks were used in statistical analysis and to obtain mean growth of 3.99 mm. based on 320 clams]

Date sampled	Clams transplanted from—							
	Western Beach		Meetinghouse Cove		Sagadahoc Bay		Bedroom Cove	
	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth
1951		*Mm.*		*Mm.*		*Mm.*		*Mm.*
April 2	44	0.0	22	0.4	26	0.0	36	0.0
May 3	37	.3	35	.6	31	.2	36	.1
June 6	42	.2	34	1.1	42	.4	39	1.2
July 5	41	.9	31	1.9	38	1.0	42	1.9
August 10	33	1.8	33	3.9	32	1.9	38	2.5
September 12	34	2.7	28	4.3	28	1.9	29	2.9
October 1	21	3.8	20	3.6	32	1.8	34	3.1
November 6	19	4.3	26	5.8	30	2.7	25	3.4
December 4*	30	3.7	30	6.0	27	1.6	29	2.9
1952								
January 20*	26	4.3	21	6.9	26	3.0	21	3.3
February 26*	28	4.0	25	5.8	32	2.7	25	4.5

TABLE A-2.—*Sagadahoc Bay test area*

[Samples collected on dates marked by asterisks were used in statistical analysis and to obtain mean growth of 16.84 mm. based on 276 clams]

Date sampled	Clams transplanted from—							
	Western Beach		Meetinghouse Cove		Sagadahoc Bay		Bedroom Cove	
	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth
1951		*Mm.*		*Mm.*		*Mm.*		*Mm.*
April 2	27	0.0	25	0.0	31	0.0	46	0.0
May 3	44	.5	41	1.0	42	.5	27	.5
June 6	18	4.6	21	5.5	35	3.3	24	4.0
June 26	28	7.1	8	8.5	35	6.0	20	8.5
August 10	16	13.7	15	14.2	42	9.7	33	13.9
September 12	21	14.6	18	18.5	34	11.3	25	16.1
October 1	22	17.4	17	21.1	19	14.1	26	17.5
November 6	10	19.8	10	17.4	22	11.5	25	18.1
December 4*	33	16.9	11	20.0	35	14.6	27	16.9
1952								
January 30*	19	15.7	15	21.1	27	15.3	13	18.2
March 11*	25	18.4	11	19.4	39	13.8	21	20.3

TABLE A-3.—*Robinhood Cove test area*

[Samples collected on date marked by asterisk were used in statistical analysis and to obtain mean growth of 15.49 mm. based on 109 clams]

Date sampled	Clams transplanted from—							
	Western Beach		Meetinghouse Cove		Sagadahoc Bay		Bedroom Cove	
	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth
1951		*Mm.*		*Mm.*		*Mm.*		*Mm.*
April 2	40	0.0	40	0.0	42	0.0	45	0.0
May 4	41	.6	40	.7	36	.4	40	.4
June 4	28	2.7	27	7.5	22	.6	20	1.6
July 2	18	5.5	21	7.0	20	4.1	14	5.2
August 9	10	8.4	4	9.5	6	3.0	6	7.6
September 12	11	17.4	10	18.2	10	12.0	12	14.6
December 7*	16	14.7	38	18.0	27	11.7	28	16.2

TABLE A-4.—*Falls Cove test area*

[Samples collected on dates marked by asterisks were used in statistical analysis and to obtain mean growth of 3.28 mm. based on 160 clams]

Date sampled	Clams transplanted from—					
	Western Beach		Meetinghouse Cove		Falls Cove	
	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth
1951		*Mm.*		*Mm.*		*Mm.*
May 2	36	0.0	42	0.1	10	0.3
June 9	34	1.4	41	1.9	4	1.2
July 6	18	1.4	30	3.1	5	.8
August 7	18	3.1	31	2.7	4	3.8
September 13	23	2.0	54	3.2	1	1.0
October 15	7	2.3	33	3.1		
November 16*	18	2.5	36	3.7	13	2.8
December 11*	29	2.1	64	3.9		
1952						
March 19	87	2.6	62	3.9		

TABLE A-5.—*Plum Island Sound test area*

[Samples collected on date marked by asterisk were all recovered dead but were used in statistical analysis and to obtain mean growth of 19.35 mm. based on 321 clams]

Date sampled	Clams transplanted from—					
	Western Beach		Meetinghouse Cove		Plum Island Sound	
	Number recovered	Average growth	Number recovered	Average growth	Number recovered	Average growth
1951		*Mm.*		*Mm.*		*Mm.*
April 30	34	1.2	41	1.3	45	1.7
May 31	30	8.9	36	10.4	36	9.9
July 2	9	18.3	33	18.0	34	17.0
August 3	3	27.0	26	23.6	10	22.7
September 7	1	20.0	1	33.0	3	23.0
December 4	3	31.7	0		2	28.5
December 4*	77	19.0	95	19.1	149	19.7

APPENDIX B.—STATISTICAL ANALYSIS

ANALYSIS OF VARIANCE BETWEEN AND WITHIN TEST AREAS

Standard deviations for the 18 groups of clams plotted against their means follow a straight line having the formula $E=1.15+0.284X$ (fig. B-1 and table B-1). The slope of this line indicates the need for transformation to make variances independent of the means in order that methods for analysis of variance shall become applicable. The fact that standard deviations plotted against means follow a straight line indicates that the log transformation is the one to be used (Quenouille 1950).

Figure B-2 shows the variance plotted against the mean for each of the 18 groups of clams after the values had been transformed by taking the log of the midpoint of each 2-mm. class plus 1 (table B-1). The very slight slope of the least-squares line, as indicated by the formula $E=0.077 - 0.0304X$, indicates that the variances have been made virtually independent of the means. Analysis of variance can therefore be completed, using the transformed values.

Table B-2 shows the completed analysis of variance of differences in mean growth between and within test areas using transformed values. The F value for a comparison of between and within test areas was 43.9, which is highly significant. This indicates that differences between growth rates in the various test areas are highly significant.

A comparison of the differences within test areas and between individuals yielded an F value of 13.0, which is also highly significant. This indicates that there is a considerable amount of variation among the groups of clams that were used in the various test areas. It appears likely from examination of the untransformed mean growths in table 1 (in text) and from the growth curves in figures 4 and 5 (in text) that Meetinghouse Cove clams are largely responsible for the high F value in this test.

TABLE B-1.—*Original and transformed mean, variance, and standard deviation for growth of 18 groups of clams in 2-mm. classes used in figures B-1 and B-2*

[Transformation is based on formula: Transformed X=log (class midpoint+1). Total number of clams, 1,186]

Group code letter	Origin	Test area	Number of clams	Original arithmetic mean (mm.)	Original standard deviation (mm.)	Trans-formed arithmetic mean	Trans-formed variance
A	Western Beach	Bedroom Cove	84	4.02	2.87	0.625	0.073
B	Meetinghouse Cove	do	76	6.15	2.72	.813	.045
C	Sagadahoc Bay	do	85	2.36	2.13	.441	.075
D	Bedroom Cove	do	75	3.57	2.38	.591	.068
E	do	Sagadahoc Bay	61	18.50	5.21	1.274	.015
F	Sagadahoc Bay	do	101	14.58	5.54	1.159	.033
G	Meetinghouse Cove	do	37	20.01	6.49	1.297	.026
H	Western Beach	do	77	16.99	5.43	1.233	.021
I	Bedroom Cove	Robinhood Cove	28	16.14	6.97	1.172	.081
J	Sagadahoc Bay	do	27	11.76	3.69	1.085	.021
K	Meetinghouse Cove	do	38	18.08	4.37	1.268	.011
L	Western Beach	do	16	14.62	5.87	1.138	.082
M	Meetinghouse Cove	Falls Cove	100	3.96	1.77	.666	.028
N	Falls Cove	do	13	2.81	1.60	.534	.050
O	Western Beach	do	47	2.37	1.78	.463	.060
P	do	Plum Island Sound	77	18.94	9.17	1.237	.075
Q	Plum Island Sound	do	149	19.72	6.67	1.283	.040
R	Meetinghouse Cove	do	95	19.15	6.63	1.269	.042

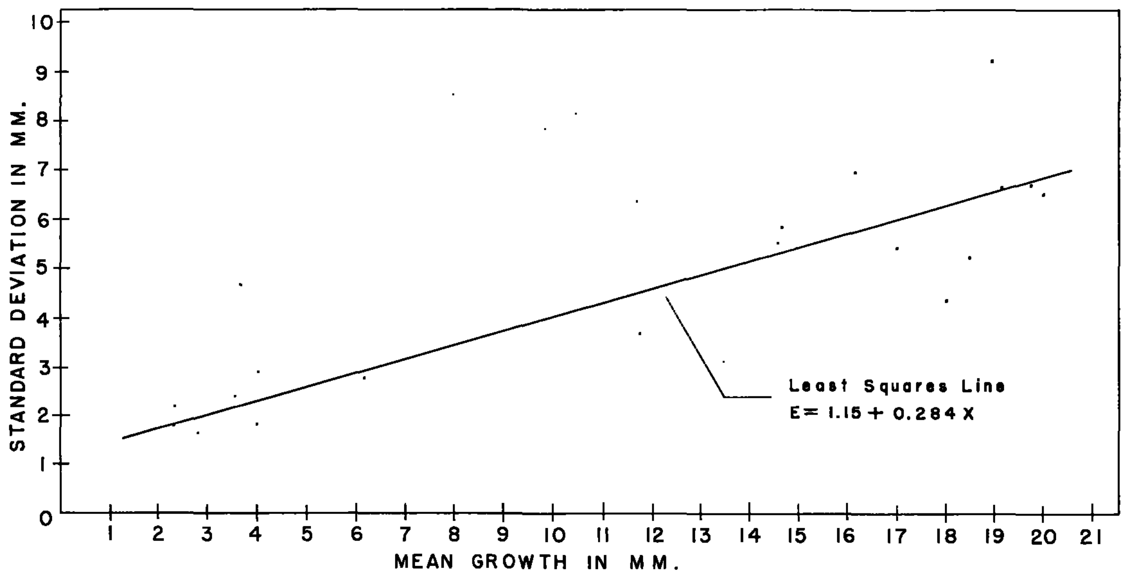

FIGURE B-1.—Standard deviation plotted against arithmetic mean growth for 18 groups of clams listed in table B-1. The slope of the trend line fitted by least-squares method indicates the need for transformation to make analysis of variance applicable.

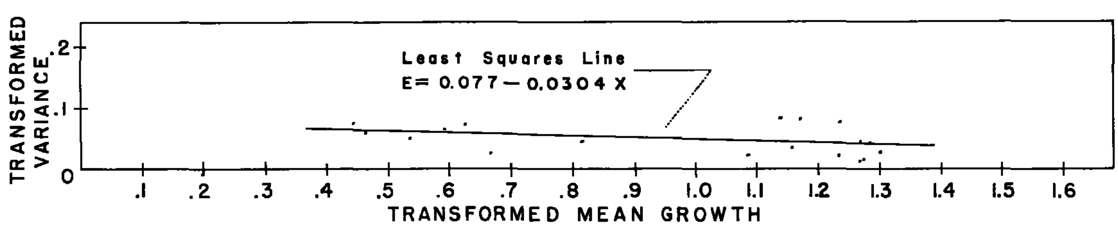

FIGURE B-2.—Variance plotted against arithmetic mean growth for 18 groups of clams listed in table B-1 after growths were grouped in 2-mm. classes and transformed by taking the log of each class midpoint plus one. The extremely slight slope of the trend line fitted by the least-squares method indicates that this transformation has made variance virtually independent of the mean, so analysis of variance method can be used.

TABLE B-2.—*Completed analysis of variance of differences in mean growth between and within test areas based on 18 groups of clams at 5 areas*

[Using values transformed by the formula: Transformed $X = \log$ (midpoint of 2-mm. class + 1)]

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Between test areas	4	114.09	28.52	**43.9
Within test areas	13	8.44	0.65	**13.0
Between individuals	1,168	53.62	0.05	
Total	1,185	176.15		

The analysis of variance by test areas was recomputed without the groups of clams that came from Meetinghouse Cove; the results are listed in table B-3. While the differences in mean growths of groups within the test areas are still highly significant, the F value has been reduced from 13.0 to 6.0 by exclusion of Meetinghouse Cove clams. Therefore, it appears that clams from this origin were responsible for more than half of the F value of 13 listed in table B-2. Also, it appears likely that the clams from Sagadahoc Bay contributed a large part of the high F value for this test (figs. 4 and 5). Since the growth pattern of both the Meetinghouse Cove clams and the Sagadahoc Bay clams was the opposite of that which might be expected had heredity been the cause of growth differences and growth rate, the significance of this F value does not alter the conclusions given here.

TABLE B-3.—*Completed analysis of variance of differences in mean growth between and within test areas based on 13 groups of clams (excluding those from Meetinghouse Cove) at 5 areas*

[Using values transformed by the formula: Transformed $X = \log$ (midpoint of 2-mm. class + 1)]

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Between test areas	4	93.32	23.33	**77.77
Within test areas	8	2.43	0.30	**6.00
Between individuals	827	42.17	0.05	
Total	839	137.92		

ANALYSIS OF VARIANCE BETWEEN AND WITHIN ORIGINS

The possibility that variation between the series means was caused by the origin of the test clams needed to be explored. Mean growths of clams from the four origins planted at Bedroom Cove, Sagadahoc Bay, and Robinhood Cove were used in this analysis, because only at these three test areas were all four groups planted. Results of the analysis-of-variance tests are shown in table B-4. The F value of 8.42 for a comparison between origins and within origins was not significant at the 5-percent level. Therefore, the effect of the origin of the clams on their growth rate after transplanting was not significant.

The F value of 166.8 for a comparison within origins and between individuals was highly significant, indicating (as would be expected) that the differences in mean growth of clams from each origin planted in the three test areas were highly significant.

TABLE B-4.—*Completed analysis of variance of differences in mean growth between and within origins of clams based on 12 groups of clams from 4 origins*

[Using values transformed by the formula: Transformed $X = \log$ (midpoint of 2-mm. class + 1)]

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F
Between origins	3	2.97	.99	8.42
Within origins	8	66.74	8.34	**166.8
Between individuals	693	31.92	0.05	
Total	704	101.63		

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