BURROWING ABILITY OF JUVENILE CLAMS

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An experiment was conducted in Feburary 1953, at the United States Fishery Laboratory in Boothbay Harbor, Maine, to study the burrowing ability of juvenile clams, Mya arenaria, (2-22mm. long), while exposed to various current velocities, and to study the effect of currents on the dispersal of the clams. The work was prompted by the fact that clams of this size are often exposed to tidal currents and wave action for varying periods, and their resulting dispersal may be an important factor in the distribution of adults. The juvenile clams become exposed either by being washed out of their burrows by storms or by voluntarily leaving their burrows to pull themselves along the surface of the flat a few inches at a time by alternately extending and contracting the foot. It is while the clams are thus wandering about that they may be "caught unawares" by an increase in wave action or current velocity, and the clams' subsequent movements become dependent upon physical forces.

The ability of young clams to move short distances about the surface of the flat by use of the foot is well known (Kellogg 1899). The fact that a continuous large-scale redistribution of juvenile clams occurs during normal weather conditions was demonstrated by Smith (1952). After more than a year of field experiments, in which he recessed square-foot trays of clamless mud in the tidal flats for short periods in Newburyport, Mass., Smith reported that "both the numbers and sizes of clams coming into a square foot area in a period of two weeks follows very closely the numbers and sizes in the open flats where they have had all season to collect."

The assistance of the following biologists of the U. S. Fish and Wildlife Service Clam Investigations is gratefully acknowledged: John B. Glude, and William J. Brown for construction of the flume, Alden P. Stickney for sediment analyses, and Osgood R. Smith for giving invaluable advice and criticism.

Materials and Methods

A wooden flume was constructed 8 feet long, 7-3/4 inches wide, and 6 inches deep (figure 1). A 2-foot section of the bottom at the upstream end and a 1-foot section at the downstream end were built up 3 inches. This provided a recess in the center, 4 feet long and 3 inches deep, to contain a miniature mud "flat" and a similar recess 1 foot long at the downstream end as a sediment trap. On the upstream end a stilling-basin was constructed 24 inches deep and 14 inches square. Thirteen inches from the bottom of this basin was a baffle with a circular opening 9 inches in diameter through which a 2-inch pipe delivered sea water about 4 inches from the bottom, the volume of flow being controlled by a gate valve. To help reduce turbulence, a piece of 14x16 mesh plastic screen was lashed

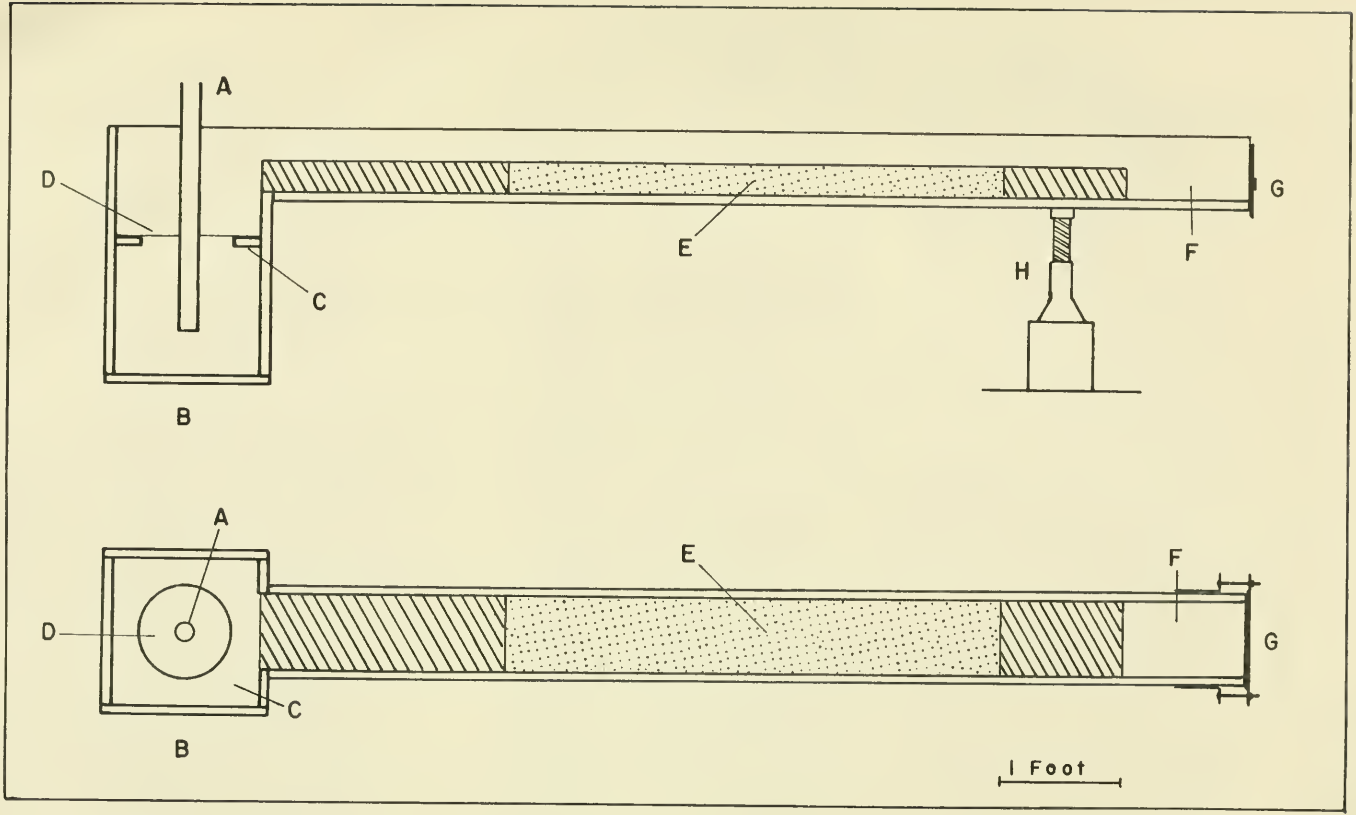

Fig. 1. Diagrams of the flume. Upper--longitudinal section. Lower--top view. A, intake pipe; B, stilling-basin; C, baffle; D, plastic screen over baffle opening; E, soil for clams; F, sediment trap; G, adjustable tailgate; H, jack.

around the pipe and fastened over the baffle opening. The discharge end of the flume was fitted with a movable tailgate to control the water depth. The slope of the flume, adjustable by means of an automobile jack, remained at 0.8% throughout the experiment.

The sediment comprising the miniature flat was collected from the upper 3 inches of a tidal flat in Hales Cove, Plum Island Sound, Mass. The uppermost layer in Hales Cove consisted of silt about one-half inch in thickness. An attempt was made to duplicate the Hales Cove flat by placing the mud in the recess while full of water and allowing the particles to settle overnight. As shown in the analysis below, the proportions of silt and fine sand were high, which, combined with considerable organic detritus, gave the sediment cohesiveness. The amount of organic material was not measured in this particular case, but samples collected from the same area contained 2.9% organic material by weight.

Particle size (microns)	Classification (Sverdrup, et al. 1942)	Percent of sample (dry weight)
under 50	silt	26.2
50-100	very fine sand	51.6
100-250	fine sand	18.2
250-400	medium sand	2.8
over 400	medium to coarse sand and larger	1.2

Three current velocities were empirically selected, based on the effects of the lowest and the highest velocities on trial groups of clams, and one which appeared to be midway between. The lowest was barely able to set in motion a few clams of a trial group, and the highest moved them all quite easily. The three velocities used were calculated to be 13, 18, and 25 cm. per second at the center of the flat (50 cm/sec = about 1 knot). Owing to the flume's slope and the resulting variation in water depth, velocities were slightly higher at the upstream end than at the downstream end. Hjulstrom (1939) states that water generally flows in a turbulent way under conditions found in nature. This is doubtless true of the three current velocities selected, although turbulence was made visible only in the 25 cm. per second current when fluorescein dye was injected into the water for this purpose.

Mean current velocities were calculated by dividing the discharge by the cross-sectional area of the water in the flume (Menard and Boucot 1951, Krumbein 1942). Admittedly, this method does not determine the velocity at the soil-water interface where friction retards a layer of water less than 1 millimeter in thickness (Menard and Boucot 1951), but it seems safe to assume that the clams extended above this layer into the turbulent flow above. The only exceptions might be a few of the smallest clams (2mm. long) which may have come to rest in minute depressions in the flat. In the present experiment, the mean current velocity is used, excluding other flow characteristics, in order that the results may be easily comparable to observations in the field--emphasis having been placed on biology rather than hydraulics.

Although practically all the clams caught in square-foot trays by Smith (1952), during two seasons of observations, were under 12 mm., the upper size limit was increased to 22 mm. in the present experiment in order to obtain additional data. Three hundred and fifty clams were measured to the nearest millimeter and separated into seven size groups of 50 each: 2-4, 5-7, 8-10, 11-13, 14-16, 17-19, and 20-22 mm. in length. Because of the limited number of juvenile clams available in winter, the same clams were used for each current velocity run.

The experimental procedure consisted of adjusting the flow to produce the desired current velocity. Then one of the groups of 50 clams was carefully "poured" into the water at the upstream end of the flat, and observations were recorded at 5-minute intervals for one-half hour. This procedure was followed for each of the seven size groups of 50 clams at the three current velocities and at zero velocity, as a control, making a total of 28 "runs." Clams which were moved by the current were noted as to type of movement, such as <u>sliding</u>, <u>rolling</u>, or <u>jumping</u>. The velocity of movement was not measured, owing to the shortness of the test area and the large number of individuals, but the rate of movement was noted in descriptive terms. The number of clams which were washed into the sediment trap and the number which burrowed were recorded. A clam which had burrowed to a point at which it was not likely to be dislodged by the current--or about to the umbones--was considered to have burrowed and was removed from the flat. This was necessary in order to recover the clams for further use before they were able to lose themselves in the sediment.

Water temperatures, recorded at frequent intervals, varied from 4.0° to 5.6° C. These low temperatures appeared to have no adverse effects on the clams, which appeared to be as active as they have been observed to be at summer temperatures.

Results

Where clams were moved by one of the three currents, the predominant type of movement was <u>rolling</u>, in which case the clams were usually oriented with the longest axis at right angles to the direction of flow. <u>Sliding</u> occurred rarely and only for distances of one-half inch or less. At 25 cm/sec current velocity, some of the smallest clams appeared to move in a combined <u>jumping</u> and <u>rolling</u> motion. In general, the smaller clams were carried downstream more easily and more rapidly than the larger, which is in agreement with the eroding velocity for coarse sand and gravel (Hjulstrom 1939).

No erosion of the flat was evident during the tests at the two lower current velocities, an elapsed time of at least 8 hours. However, after about 4 hours' experimentation at a current velocity of 25 cm/sec a very small accumulation of sand particles was noted on the wooden flume bottom just downstream from the "flat". The flat itself appeared to be unchanged. Hjulstrom's (1939) curve for erosion and deposition of uniform material shows that the velocity required to erode sediments is high for coarse particles, lowest for medium sand (about 20 cm/sec), and rises again as the particles decrease in diameter. This apparent contradiction is due to the fact that the curve of Hjulstrom refers to uniform sediment and hence does not apply to the flat in the present experiment. The large proportion of silt and very fine sand, together with organic detritus, probably gave the latter sediment sufficient cohesiveness to withstand erosion. The relatively high velocity of current required to erode clay is a comparable example.

The results of the 28 runs are given below in 4 sections labeled with the appropriate current velocities. In the graphs (Figs.2-4) the clams of similar behavior have been placed in four size groups instead of seven, for clarity and convenience. The results are presented in greater detail in tables 1 and 2.

Mean current velocity of 13 cm. per second

Clams of all seven size groups were moved to a similar extent by a current flowing 13 cm. per second. A few of each size group were dispersed downstream a few inches at a time, most proceeding no farther than half the length of the flat. The predominant type of movement was slow and intermittent rolling. Sliding occurred rarely and never more than one-half inch. At the end of 30 minutes only 2.3% of the seven groups of clams were in the sediment trap. The smallest clams appeared to be moved most rapidly as the percentage of them landing in the trap would indicate (fig. 2).

In comparing the burrowing rates of the various size groups, it was noted that the smaller the clams, the faster they were able to burrow as shown by the curves in figure 2. Of the 2-7 mm. clams, 20% were burrowed in 5 minutes, 59% in 10 minutes, and 84% at the end of 30 minutes. In contrast are the 20-22 mm. clams, only 2% of which burrowed in 15 minutes and only 40% in 30 minutes. The intermediate size groups conformed to this general pattern, the 8-13 mm. clams starting slowly but equalling the 2-7 mm. clams after 30 minutes, while the 14-19 mm. clams started more slowly and 66% burrowed in 30 minutes (fig. 2).

Of the seven size groups of clams combined, 72.5% were able to burrow in 30 minutes, while 2.3% were washed into the sediment trap and 25.2% remained inactive on the surface of the flat.

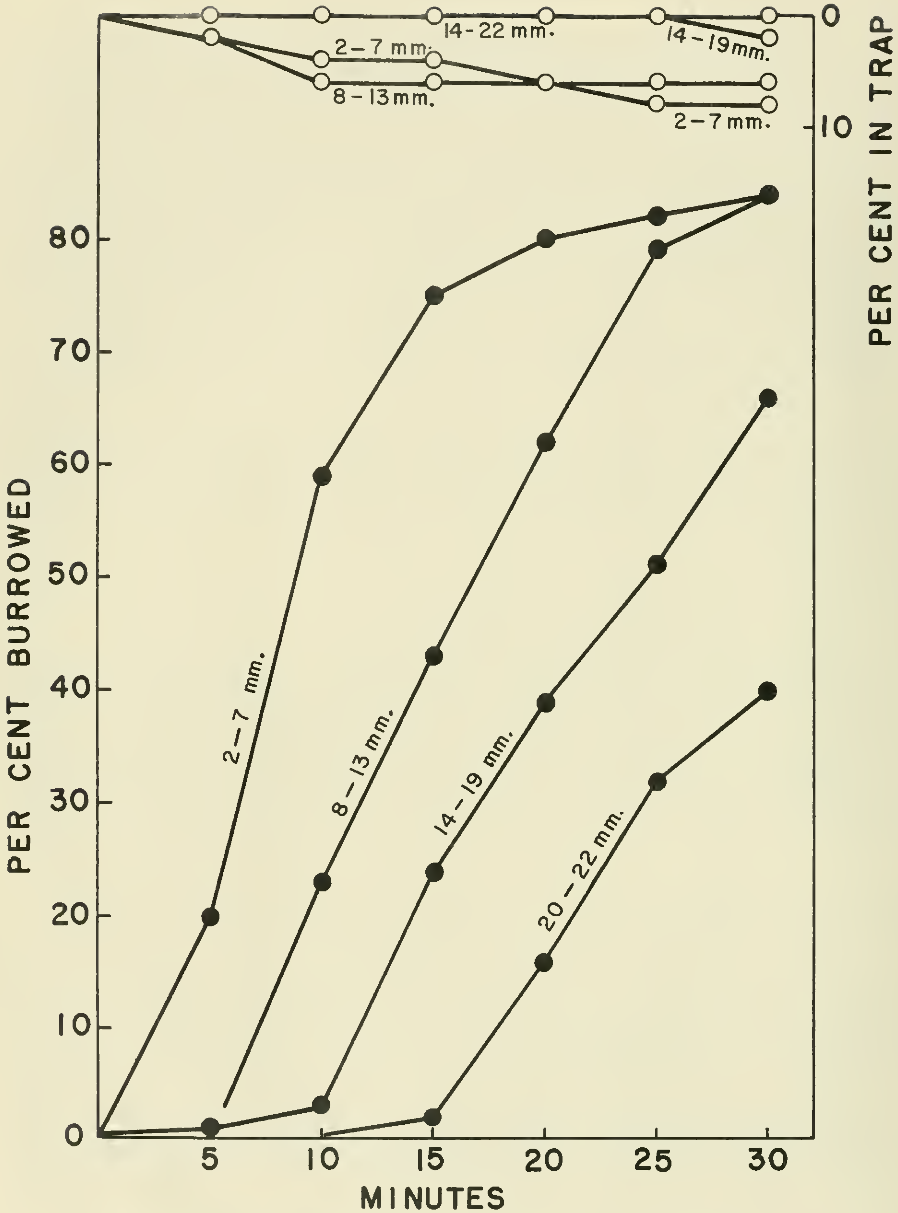

Fig. 2. The burrowing ability of juvenile clams of various sizes exposed to a current velocity of 13 cm. per second. Solid circles -- Cumulative percentage of clams which burrowed. Open circles -- Cumulative percentage of clams washed into sediment trap and therefore unable to burrow. The corresponding size groups together with the inactive clams (not represented) total 100% at any given time.

Mean current velocity of 18 cm. per second

A current velocity of 18 cm. per second had diverse effects on the seven size groups of clams tested. Clams of the smaller four size groups (2-13 mm.) were dispersed fairly rapidly along the entire length of the "flat". Movement was both by rolling and by sliding. At the end of 30 minutes, about 32% of the above size groups were in the sediment trap.

Clams of the larger three size groups (14-22mm.) showed a tendency to jam together, probably as a result of occupying more relative space on a limited flat. They rolled more slowly than the smaller clams and remained mostly along the upstream half of the "flat". Only 21% of the clams from 14-22 mm. reached the sediment trap in 30 minutes.

The graph in figure 3 indicates a burrowing activity similar to that at 13 cm. per second (fig. 2), except the clams were somewhat slower in starting to burrow in the 18 cm. per second current. A few clams of various sizes which had obtained footholds were finally dislodged after making prolonged efforts to burrow broadside to the current. Of the clams in the seven size groups, only 48.8% were able to burrow in 30 minutes, while 27.1% landed in the trap and 24.1% remained on the flat but did not burrow.

Mean current velocity of 25 cm. per second

The effect of a current velocity of 25 cm. per second was severe on all sizes of clams, movement being continuous and rapid. The type of movement was both rolling and sliding and was most rapid in the smaller size groups, as in the other two current velocities. Indeed, many of the 2-4 mm. clams spent part of their journey downstream out of contact with the flat, their movement being a combination of rolling and jumping. Large numbers of clams of all size groups were washed into the trap within 1 or 2 minutes. Within 5 minutes 89.4% of the total number of clams were in the trap, and at the end of 30 minutes 98% of the clams were in the trap. As in the 18 cm. per second tests, the larger clams held one another stationary by clumping together, but in this case the "clumps" were washed into the trap en masse in a very short time. The severity of the current was such that only 1.7% of the total number of clams were able to burrow, 0.3% remaining inactive on the flat.

Zero current velocity (control)

The trials at zero current velocity were conducted the week following the above trials. Although the clams were relatively slow in beginning to burrow during the first 10 minutes, 68% of those under 14 mm. were burrowed by the end of 20 minutes; at the end of 30 minutes 84% were burrowed. The 14-19 mm. clams burrowed at similar rates to those in the previous trials, but the 20-22 mm. clams were somewhat slower. (Compare figures 2, 3, and

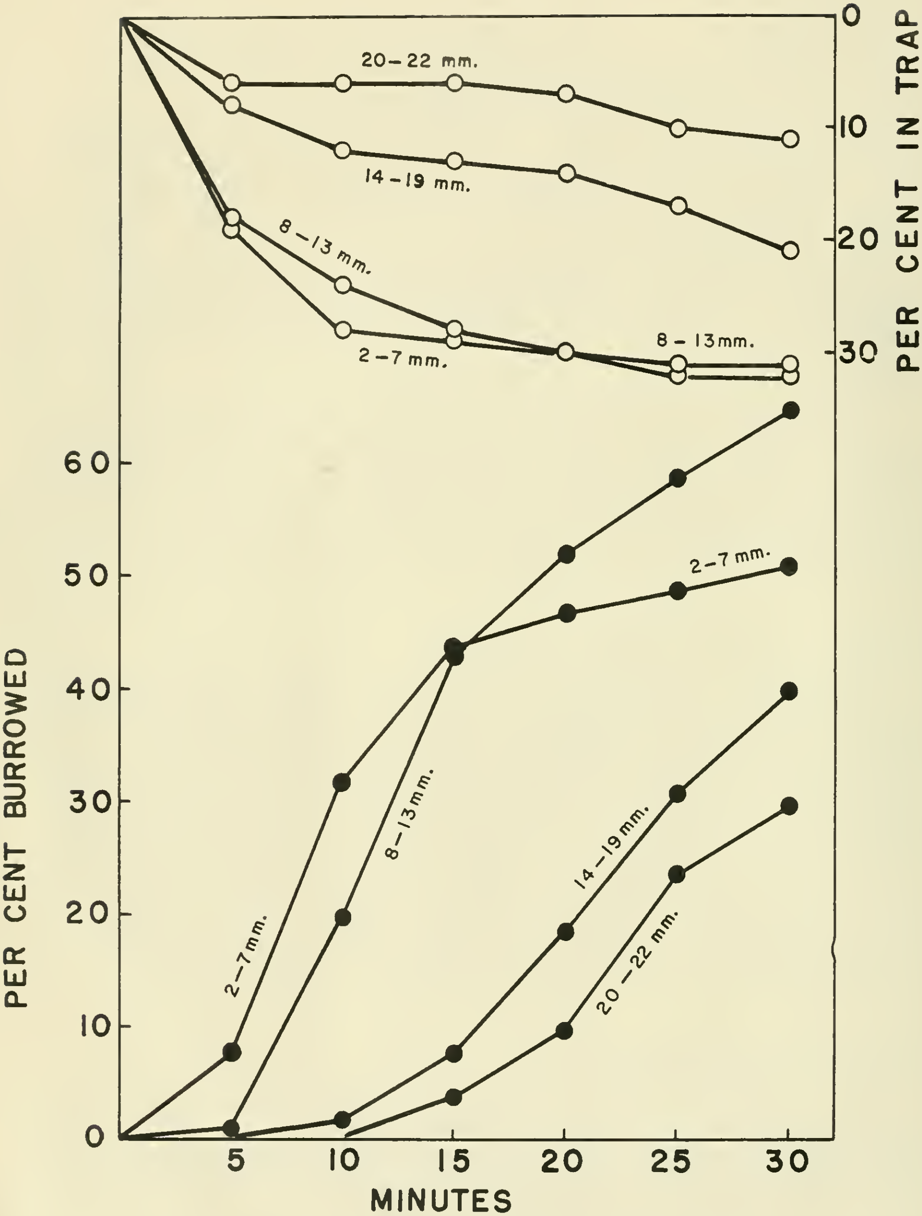

Fig. 3. The burrowing ability of juvenile clams of various sizes exposed to a current velocity of 18 cm. per second. Solid circles -- Cumulative percentage of clams which burrowed. Open circles -- Cumulative percentage of clams washed into sediment trap and therefore unable to burrow. The corresponding size groups together with the inactive clams (not represented) total 100% at any given time.

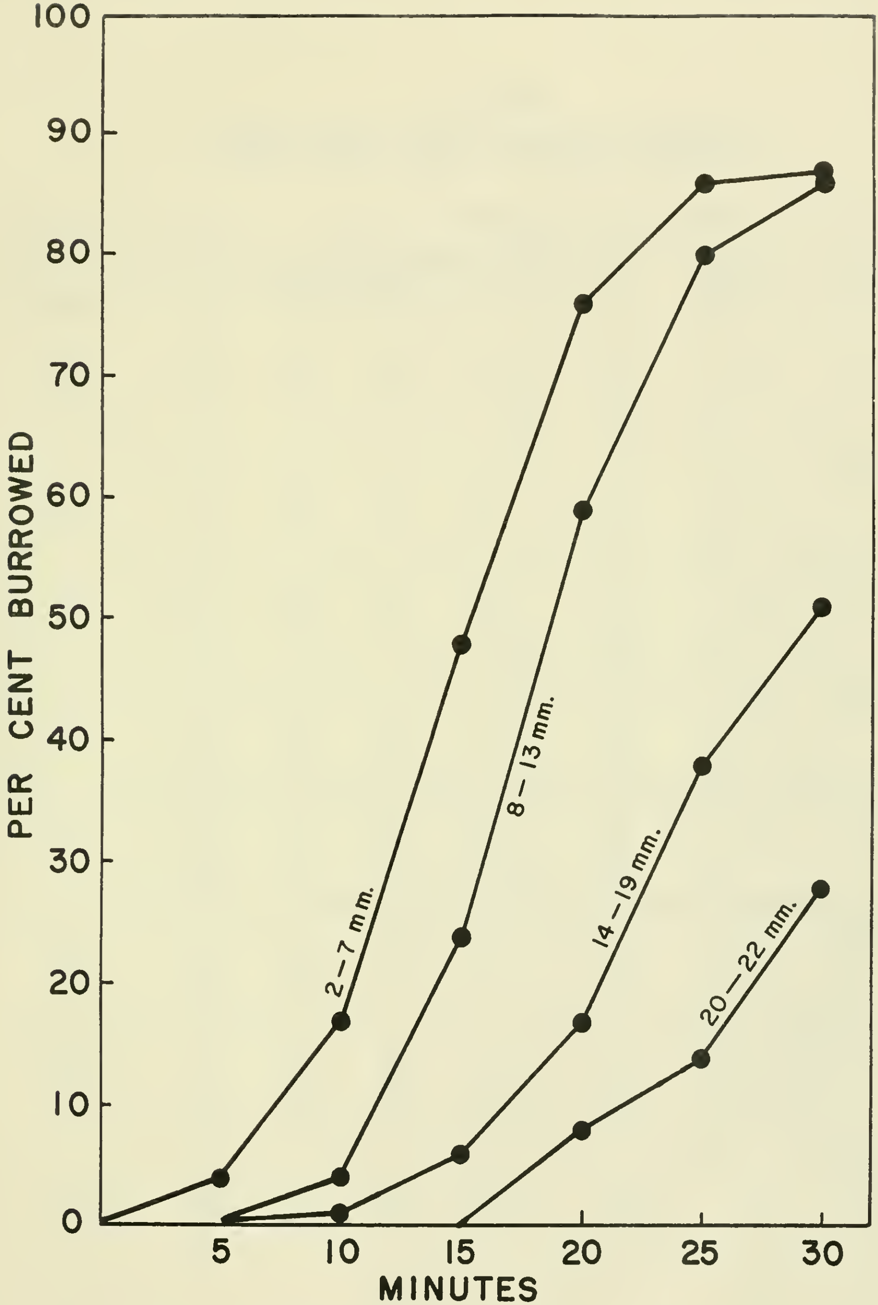

Fig. 4. The burrowing ability of juvenile clams of various sizes in the absence of current (Control).

Table 1

Percentages of juvenile clams of various sizes washed into sediment trap by three current velocities

Size-group	Current velocity (cm/sec)	Percentage of clams washed into trap					
		Minutes					
		5	10	15	20	25	30
2-4 mm.	13	0	0	0	0	0	0
	18	22	28	28	30	34	34
	25	100	100	100	100	100	100
5-7 mm.	13	2	4	4	6	8	8
	18	16	28	30	30	30	30
	25	94	96	96	96	96	96
8-10 mm.	13	0	0	0	0	0	0
	18	24	30	36	39	40	40
	25	92	92	94	94	94	94
11-13 mm.	13	2	6	6	6	6	6
	18	12	18	20	22	22	22
	25	90	94	96	98	98	98
14-16 mm.	13	0	0	0	0	0	0
	18	10	12	14	16	18	22
	25	98	100	100	100	100	100
17-19 mm.	13	0	0	0	0	0	2
	18	6	12	12	12	16	20
	25	72	88	96	98	100	100
20-22 mm.	13	0	0	0	0	0	0
	18	12	12	12	14	20	22
	25	80	90	96	96	98	98
Combined (2-22 mm.)	13	0.5	1.4	1.4	1.7	2.0	2.3
	18	14.6	20.0	21.7	23.1	25.7	27.1
	25	89.4	94.3	96.8	97.4	98.0	98.0

Table 2

The burrowing rates of juvenile clams of various sizes in still water and when exposed to currents.

Size-group	Current velocity (cm/sec)	Percentage of clams burrowed					
		Minutes					
		5	10	15	20	25	30
2-4 mm.	0	8	28	56	72	74	76
	13	34	64	74	82	84	88
	18	10	30	42	42	44	44
	25	0	0	0	0	0	0
5-7 mm.	0	0	6	40	80	98	98
	13	6	54	76	78	80	80
	18	6	34	46	52	54	58
	25	4	4	4	4	4	4
8-10 mm.	0	0	6	8	66	84	92
	13	0	38	60	76	90	92
	18	2	28	56	56	58	60
	25	2	2	2	2	2	4
11-13 mm.	0	0	2	40	52	76	80
	13	0	8	26	48	68	76
	18	0	12	30	48	60	70
	25	0	2	2	2	2	2
14-16 mm.	0	0	0	2	16	26	42
	13	2	6	34	50	58	76
	18	0	0	4	16	38	48
	25	0	0	0	0	0	0
17-19 mm.	0	0	2	10	18	50	60
	13	0	0	14	28	44	56
	18	0	4	12	22	24	32
	25	0	0	0	0	0	0
20-22 mm.	0	0	0	0	8	14	28
	13	0	0	2	26	32	40
	18	0	0	4	10	24	30
	25	0	0	0	0	0	2
Combined (2-22 mm.)	0	1.2	6.6	23.6	47.1	63.7	70.0
	13	6.0	24.3	40.8	55.4	65.1	72.5
	18	2.6	15.4	27.7	35.1	43.1	48.8
	25	0.8	1.1	1.1	1.1	1.1	1.7

4.) Of the clams in all seven size groups, 70% were burrowed at the end of 30 minutes. This percentage was 2.5 lower than the percentage burrowed at 13 cm. per second.

Conclusions

As previously mentioned, the effects of currents on various sizes of juvenile clams were similar in some ways to those on coarse sand and gravel. However, the important difference between clams and sediments, outside of shape and specific gravity, is that clams are alive and have some influence over their own dispersal. This has been emphasized in the foregoing results by the fact that the smaller clams (2-13 mm.) which were moved most extensively by the currents also burrowed more rapidly and in larger numbers per allotted time than did the larger clams (14-22 mm.). The explanation for this seeming paradox lies in the greater activity and superior burrowing ability of the smaller clams, which is partly due to the relatively larger foot. While the clams are being moved along by the current, there are brief intermittent periods when they become stationary, enabling the small, active clams to extend the foot quickly and burrow. On the other hand, the larger, less active clams, which require longer periods at rest in order to extend the foot, are repeatedly set in motion before they can begin to burrow. Also contributing to the successful burrowing of the small clams are minute depressions in the flat which afford some protection from the full impact of the current.

According to the data presented, there appears to be a natural line of demarcation of juvenile clams at about 13 mm. below which they are very active and above which they become progressively less active. This is significant in view of the fact that almost all the clams of Smith's (1952) movement trays were under 13 mm. in length, probably indicating that clams over 13 mm. are beginning to acquire the sedentary habits of mature clams.

In attempting to interpret field conditions in the light of the results herein, many natural factors should be considered, such as water depth, wave action, variation in current velocities through tidal cycles, and type of sediment. For instance, wave action may prevent the burrowing of exposed clams by constantly agitating them, even though the current velocity may be too slow to move the clams. Oftentimes the ability of a clam to burrow may depend upon the stage of the tide, which governs the velocity of the tidal currents. It would be relatively easy for the clam to burrow near slack ebb or slack flood tide, but difficult at mid-tide. However, clams which are able to withstand the high-velocity currents of mid-tide by byssus attachment or by landing in depressions would be able to burrow at the approach of slack tide.

When a flat is composed of shifting sand, juvenile clams may be alternately eroded from their shallow burrows and buried by the moving sand ripples. The result in this process is that the clams die and end up as windrows of empty and broken shells. An example of this recently occurred in the Parker River in Newbury, Mass. A screened sample of the flat on September 23, 1954, yielded 490 juvenile clams (2-18mm. long) per square foot. On October 22, 1954, a similar sample yielded only 44 clams per square foot, the largest of which was 6 mm. in length; but the sampler contained many shell fragments of juvenile clams of the size range found in the first sample.

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