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THE EFFECTS OF AN EXPERIMENTAL HYDRAULIC HARVESTER ON MARGINAL AND SUBMARGINAL RAZOR CLAM (*Siliqua patula* Dixon) HABITAT ON THE COPPER RIVER DELTA, CORDOVA, ALASKA

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Richard B. Nickerson

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Timothy J. Brown

STATE OF ALASKA
Jay S. Hammond, Governor
DEPARTMENT OF FISH AND GAME
Ronald O. Skoog, Commissioner
Subport Building, Juneau 99801

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Timothy J. Brown

Alaska Department of Fish and Game
Division of Fisheries Rehabilitation, Enhancement and Development
Cordova, Alaska

ABSTRACT

The effects of an experimental hydraulic harvester on clay levels in marginal and submarginal razor clam habitat was analyzed from two latin squares. Post-treatment clay levels in the marginal habitat did not differ significantly from respective pre-treatment levels. Clay levels increased significantly in control plots of the submarginal habitat, but were significantly reduced in horizontally flushed plots.

INTRODUCTION

Rapidly changing environmental conditions have had an adverse effect upon razor clam (Siliqua patula Dixon) habitat along the Copper River delta. Optimal razor clam habitat was drastically reduced to submarginal by natural processes between 1958 and 1964. Marginal habitat is that in which razor clams are scarce or rarely found. Submarginal habitat is that in which the species cannot live.

Razor clam habitat conditions along the Copper River delta as reported by Reimnitz (1966) are dominated by the following factors: 1) the cold northern climate, which permits glacier formation in most of the Copper River tributaries, restricts the very coarse sediment supply of 107×10^6 metric tons/year to a few summer months; 2) tectonic instability which results in crustal warping and strong seismic shocks; and 3) intense marine reworking of sediments due to a large tidal range, strong ocean currents, and frequent large storm waves. Despite a relatively limited drainage area of 63000 km^2 and a water discharge of 0.08×10^{12} m^3/year compared to that of the Amazon (6.30 $km^2 \times 10^6$; 6.70×10^{12} m^3), the Copper River discharges more than three times the amount of dissolved solids (114.1 ppm) and nearly one-third the volume of sediments as the Amazon (347×10^6 metric tons); thus indicating the relative importance of the Copper River in contributing sediments to the ocean (Reimnitz 1966).

From 1916 to the late 1950's, the City of Cordova boasted of being the "razor clam capital of the world". However, mass mortality of razor clams was attributed to an unusually heavy deposition of rock flour following spring breakup of the Copper River in 1958 (Nickerson 1975). Subsequently, the recovery of razor clam populations by recruitment was slow and the fishery appeared to be operating on older age classes (Tegelberg 1961). Then the impact of the March 27, 1964 Good Friday Earthquake was felt.

Reimnitz (1966) reported that a nearly 2m landmass uplift was associated with the earthquake at Cordova and tsunamis as high as 7.5 m eroded at least 76 cm of surface sediment from large portions of the tidal flats. The stresses generated by the ground motion during the earthquake produced numerous sedimentary structures that are preserved in the sedimentary column. These include sand dikes, sand pipes, slumps, faults, and joints. Some of these features were caused by a reorientation of the grain to grain relationship. Reimnitz (1966) also found that the most characteristic features of the intertidal deposits were textural variability over short distances, abundant ripple marks, layering, lamination, and cross-bedding of sand, silt, and clay materials.

The change in sedimentary characteristics from optimal to marginal and submarginal razor clam habitat is also reflected by increasing densities of cockles (Clinocardium nuttalli Conrad), surf clams (Spisula polynyma Stimpson), and soft-shell clams (Mya arenaria Linnaeus). The latter species coexist with S. patula in marginal habitat, but are not found in optimal habitat (Nickerson 1975).

Alaska became a member of the National Shellfish Sanitation Program (N.S.S.P.) in 1975. The razor clam was the only molluscan species authorized for interstate commerce (fresh or frozen for human consumption). Hydraulic clam harvesters became legal gear for razor clams in 1976. Prior to the legalization of hydraulic harvesters, Alaska Packers Association, in 1963, tested a hydraulic harvester for catchability, but not for its effects on the habitat (Nickerson 1975). Hence we initiated research on the impact of hydraulic harvesting in the Cordova area using an experimental model, prior to authorization of commercial models (Nickerson 1977).

An inverse relationship was found to exist in the Cordova area between clay levels (particles <0.005 mm in diameter) in razor clam bearing substrate and the presence of 1-year-old razor clams (Nickerson 1975). That is, the density of 1-year-old clams decreased as levels of clay increased. When clay levels reached 2.2% of the substate composition, 1-year-old razor clams were not found. Removal of some clay fractions from the substate by hydraulic harvesters was considered to be a possible asset to razor clam production. Determination of changes in clay levels was the major goal of the study.

Some investigators working with hydraulic harvesters and their effects on intertidal soft-shell clam habitat found that finer sediments were removed as a direct result of the natural sorting process caused by the forceful suspension of sediments (Manning 1957; Haven 1970; Kyte et al. 1975; Kyte and Chew 1975). Pfitzenmeyer (1972) found that because of the very low silt-clay content and uniform nature of the sediments, no observable loss of fines from harvesting occurred, but sediment in the dredge scars was noticeably less firm or compact for at least 1 year after harvesting. Haven (1970), however, found that a harvester did remove a significant percentage of the silt-clay sediment fraction. Similar results were obtained by Godcharles (1971). Neither Haven nor Godcharles performed compactness analyses. A harvester study conducted in Washington also showed a reduction in fines, but no information was obtained on compactness of harvesting scars (Kyte and Chew 1975).

The belief that hydraulic harvesting benefits future sets of larval soft-shell clams through tilling the sediment has been expressed (Kyte and Chew 1975). Pfitzenmeyer (1972) found increased survival and recruitment rates in dredged tracts. Kyte et al. (1975) found significant increases of spat and juveniles in dredged tracts.

The senior author (Nickerson) testified before the Alaska Board of Fish and Game in April in 1974 regarding his belief that: 1) hydraulic harvesters would allow Alaska to efficiently crop its extensive razor clam stocks (compared to hand dug costs) and thereby compete favorably with other member states and nations of the N.S.S.P.; and 2) they were, perhaps, the only tool capable of countering the dynamics of habitat change on the Copper River delta for the benefit of razor clam production. This testimony laid the foundation for subsequent testing and legalization of hydraulic harvesters.

METHODS

Two 3 x 3 latin squares in linear form (Steel and Torrie 1960) were staked out using power auger and spruce poles at a representative site in Orca Inlet, Prince William Sound during April, 1973 (Figure 1). The site was in the lee of an extensive clay-mud bank which had been stripped of sand-silt material following the 1964 earthquake. Individual plots were 3m square. They were spaced 4.6 m apart to avoid interaction during testing. The first square, with plots designated A,B,C (A-C), occupied a zone considered to be marginal habitat due to low densities of razor clams as determined from a previous study (Nickerson 1975). This square occupied the low tide terrace from the -0.20 m to the +0.24 m tide levels relative to mean lower low water. Square A-C formed the seaward bank of a main tidal channel. The second square, plots D,E,F (D-F), occupied a zone considered submarginal as no razor clams were found there. Visual inspection indicated a much higher silt and/or clay content than observed in A-C. Square D-F was located between the +0.05 m and +0.31 m tide level and was situated at the junction of two tidal channels. Both squares were on the same bar, faced the same direction and were separated by a distance of 100 m to avoid interaction of treatments. Duration of the study was from April, 1973 to May, 1974.

Initially eight samples of substrate, each 0.03 m^2, were removed from randomly selected locations in each plot of both squares. The substrate was washed through a screen to find 1-year-old clams. Next, eight "Before" substrate cores were obtained from each plot at randomized locations. An open cylinder (6.5 x 10 cm I.D.) was used as a corer. Treatments were then assigned. The A and D plots served as controls; they received no flushing from the model harvester, (modified after MacPhail and Medcof 1962). Vertical flushing was designated for the C and F plots.

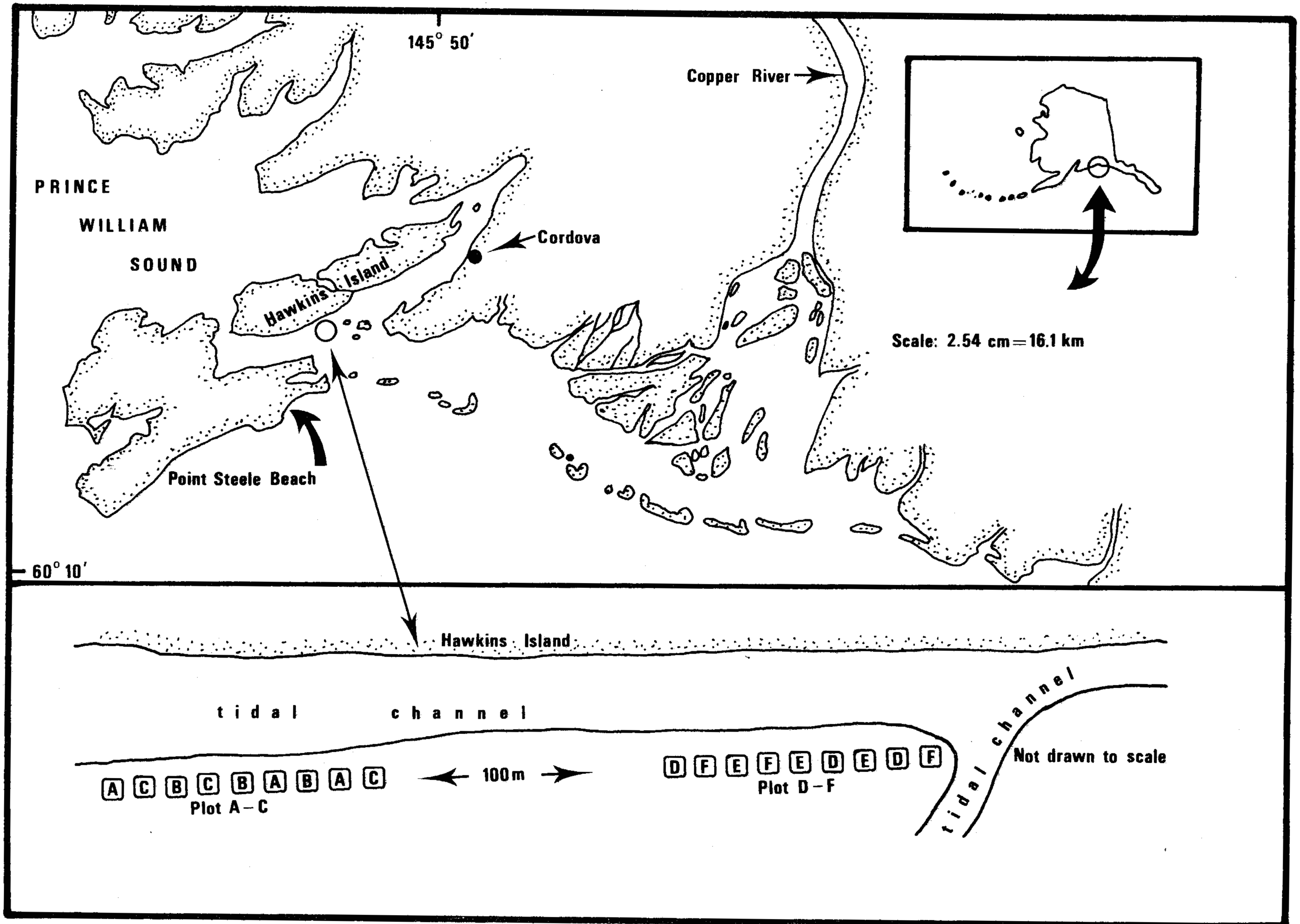

Fig. 1 Location of plots A-C and D-F.

Relocating the handle of the harvester allowed vertical and horizontal flushing (Figure 2). Water, in vertical flushing, was directed onto the surface of the substrate from above. Horizontal flushing was accomplished by submerging the manifold in the substrate to a depth of 0.46 m and directing the water forward. A high pressure pump delivering 4542 l/h (1200 gal/h) at 18.7 kg/cm^2 (105 lbs./in.^{2}) was connected to the harvester by a 30 m length of 6.35 cm diameter fire hose. Flushing began at an upper corner of a plot and the harvester was moved back and forth until the entire area of the plot received the treatment.

The reasons for using a modified MacPhail-Medcof harvester were: 1) its construction and operating costs were within budget restrictions, 2) its size complemented the statistical design of the experiment, and 3) its use in studies by MacPhail and Medcof (1962) on soft-shell clams and by Bourne (1967) on butter clams (Saxidomus giganteus Deshayes) demonstrated its efficiency, 4) its operating characteristics simulated the action of a commercial Hanks harvesters and a razor clam harvester developed and used in British Columbia (Nickerson 1975) through vertical flushing, and 5) it simulated proposed (by the senior author) prototypes specifically for razor clams through horizontal flushing which intercepts the burrowing mollusc and simultaneously establishes a fluid medium causing the clam to be uncontrollably suspended in preparation for capture.

In 1973, square A-C received treatments on May 3. Eight "After" (i.e., post treatment) substrate cores were collected on May 5. The E plots in square D-F received treatment on May 16, and F plots were treated on May 17. Eight each "After" substrate samples were collected from E plots on May 18 and from D and F plots on May 19. Sub-samples of substrate were selected at random from plot totals and analysis followed standard procedures of the American Association of State Highway Officials (1971) using 200 g samples (as suggested by J. Lindsey, Director, Soils Laboratory, Alaska Department of Transportation, Valdez).

In order to determine how well young razor clams would survive in plot A-C, a sample of clams was obtained on June 3 by screening substate at Point Steele beach, Hinchinbrook Island which is 12.9 km from squares A-C and D-F. A previous study revealed an abundance of young razor clams at Point Steele beach (Nickerson 1975). On June 6, 15 clams, each marked with an "X" scratched in the periostracum, were planted within a 0.3 m circle at the center of each plot in square A-C.

One year later (1974) substrate at the center of each plot in square A-C was screened on May 4 and 5 to assess survival of the transplanted razor clams. A penetrometer was randomly applied eight times each to plots in square D-F on May 7 to evaluate texture and firmness.

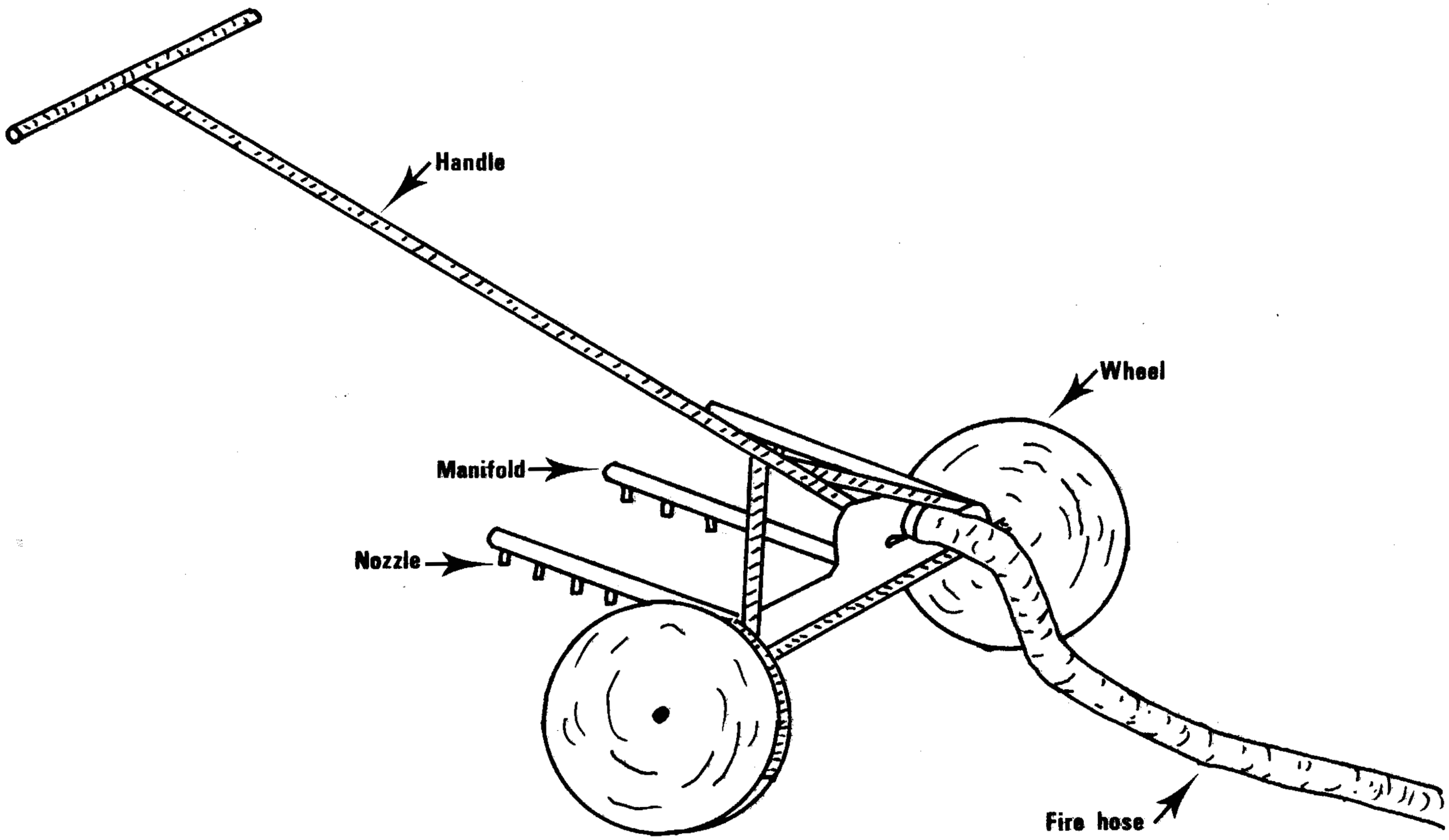

Fig. 2 Experimental hydraulic harvester (after Nickerson, 1977).

The penetrometer was constructed from local materials consisting of a 71 cm length of oak board, 2 cm thick, and 6.4 cm wide for all but 15 cm of its length. the 15 cm penetrating end was 1.9 cm square with pointed end and graduated 1 cm increments by color coded map tacks with plastic heads. A scale housing, made from wire cloth and epoxy plastic, was affixed to the opposite end. Figure 3 illustrates the design. A spring scale graduated in 1 pound (0.45 kg) increments from 0 to 50 pounds (0 to 22.7 kg) was secured within the housing and a handle attached to the weighing mechanism. The device was operated by pushing the pointed end into the substrate, then forcing both hands down on the handle. Results were recorded by depth in cm penetrated and pressure exerted to achieve that depth.

RESULTS AND DISCUSSION

Only one 2.5 year old clam was recovered from the initial screening; location of recovery was B2.

Analysis of variance in latin square of A-C "Before" substrate (the mean clay contents are given in Table 1) implied no difference in clay levels among treatment means: F = 1.08, (d.f. = 2, 2), P = .48. Analysis of variance of "After" A-C substrate indicated significant differences in clay levels among treatment means: F = 47.6 (d.f. = 2, 2), P = .02, which implies that clay levels increase with horizontal flushing. Analysis of covariance in latin square (Snedecor 1950) of "Before" vs "After" A-C substrate revealed that differences in clay levels bordered on significance: F = 115.2, (d.f. = 2, 1), P = .07. Table 2 summarizes the above data with "t" tests and further implies that post-treatment clay levels in horizontally flushed plots were higher than in post-treatment vertically flushed and control plots.

Analysis of variance in latin square revealed no difference in clay levels among D-F "Before" or "After" substrate: F = 8.67, (d.f. = 2, 2), P = .10; F = 3.58, (d.f. = 2, 2), P = .22, respectively (see Table 3 for the mean contents). "After" substrate clay levels differed significantly only between the control and horizontally flushed plots t = 2.88, (d.f. = 16), P < .02.

Analysis of covariance of "Before" vs "After" D-F substrate implied that differences in clay levels bordered on significance: F = 102.6 (d.f. = 2, 1), P = .07 (i.e., clay levels were reduced in flushed plots). Table 4 summarizes the above data with "t" tests.

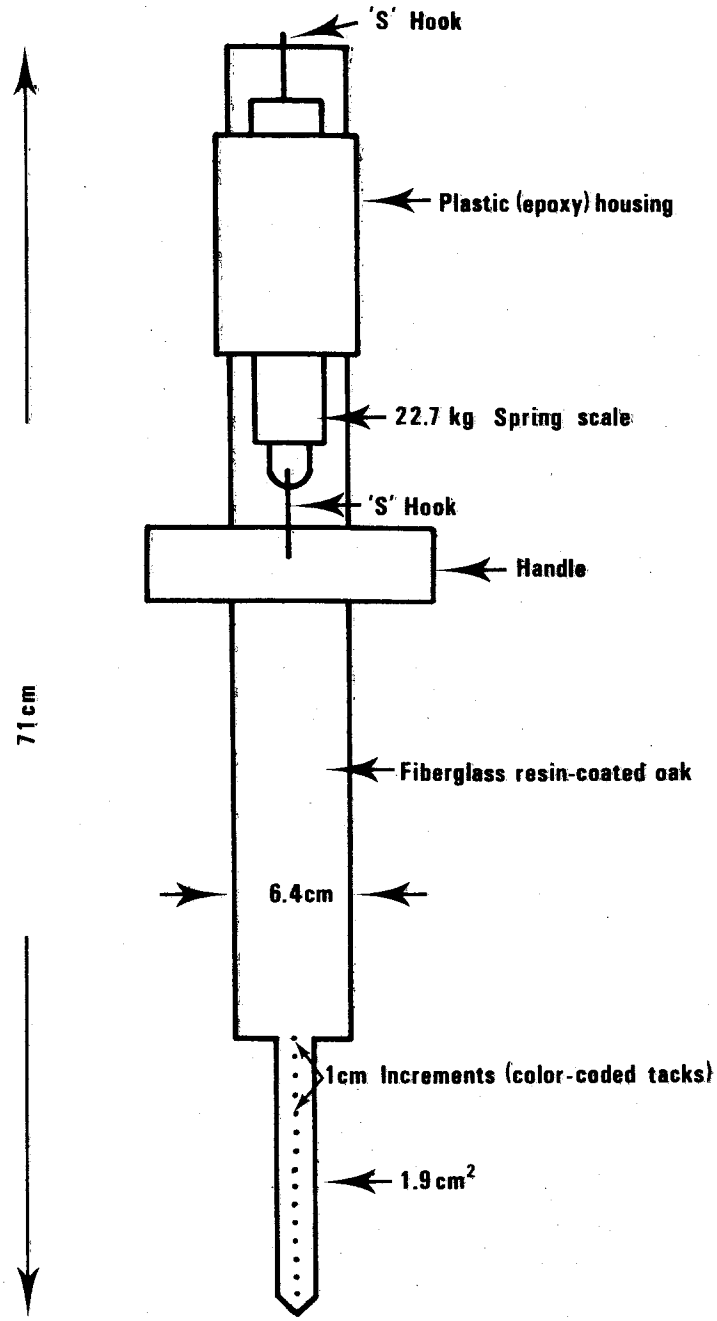

Fig. 3 Penetrometer designed for use in plots A-C and D-F.

Table 1. Mean clay content (g) before (X) and after (Y) treatment in latin square A-C where A plots received no flushing, B plots received vertical flushing and C plots received horizontal flushing.

Row	X Y	Column (Sample Size) 1	2	3
1		C1	A1	B1
	X	2.38(2)	3.09(2)	2.02(2)
	Y	4.52(2)	2.38(2)	1.78(2)
2		A2	B2	C2
	X	2.22(2)	2.68(2)	1.85(2)
	Y	3.30(2)	2.29(2)	3.96(2)
3		B3	C3	A3
	X	2.62(2)	6.72(2)	3.33(2)
	Y	2.82(2)	5.09(2)	2.85(2)
Treatment		A	B	C
Means	X	2.88	2.44	3.65
	Y	2.84	2.30	4.52

Table 2. Means (g), variances and sample sizes for clay content from latin square A-C with results of "t" tests. A = control, B = vertical flushing and C = horizontal flushing.

BEFORE			AFTER		
$\bar{A} = 2.88$	$s^2 = 0.60$	N = 6	$\bar{A} = 2.84$	$s^2 = 0.38$	N = 6
$\bar{B} = 2.44$	$s^2 = 0.65$	N = 6	$\bar{B} = 2.30$	$s^2 = 0.91$	N = 6
$\bar{C} = 3.65$	$s^2 = 5.91$	N = 6	$\bar{C} = 4.52$	$s^2 = 2.48$	N = 6

Square A-C "Before"

A vs B t = 0.97; t.95 (d.f. 10) = 2.228; $P>.05$

A vs C t = 0.74; t.95 (d.f. 10) = 2.228; $P>.05$

A vs C t = 1.16; t.95 (d.f. 10) = 2.228; $P>.05$

Square A-C "After"

A vs B t = 1.18; t.95 (d.f. 10) = 2.228; $P>.05$

A vs C t = 2.43; t.95 (d.f. 10) = 2.228, $P<.05$

B vs C t = 2.96; t.975 (d.f. 10) = 2.764, $P<.02$

Table 3. Mean clay content (g) before (X) and after (Y) treatment in latin square D-F where D plots received no flushing, E plots received vertical flushing and F plots received horizontal flushing.

Row	X Y	Column (Sample size)		
1		F1	D1	E1
	X	6.66(4)	6.41(2)	7.76(2)
	Y	5.21(4)	8.33(2)	6.94(2)
2		D2	E2	F2
	X	6.18(2)	6.66(4)	7.80(4)
	Y	7.25(2)	3.82(2)	6.16(4)
3		E3	F3	D3
	X	6.60(4)	6.70(4)	6.88(2)
	Y	7.29(4)	6.06(4)	8.74(2)
Treatment		D	E	F
Means	X	6.49	7.01	7.05
	Y	8.11	6.02	5.81

Table 4. Means (g), variances and sample sizes for clay content from latin square D-F with results of "t" tests. D = control, E = vertical flushing and F = horizontal flushing.

BEFORE			AFTER		
$\bar{D} = 6.49$	$s^2 = 0.30$	N = 6	$\bar{D} = 8.11$	$s^2 = 1.93$	N = 6
$\bar{E} = 6.85$	$s^2 = 0.70$	N = 10	$\bar{E} = 6.34$	$s^2 = 5.43$	N = 8
$\bar{F} = 7.05$	$s^2 = 0.98$	N = 12	$\bar{F} = 5.81$	$s^2 = 2.81$	N = 12

Square D-F "Before"

D vs E t = 0.95; t.95 (d.f. 14) = 2.145; P>.05

D vs F t = 1.28; t.95 (d.f. 16) = 2.120; P>.05

E vs F t = 0.50; t.95 (d.f. 20) = 2.086; P>.05

Square D-F "After"

D vs E t = 1.65; t.95 (d.f. 12) = 2.179; P>.05

D vs F t = 2.88; t.975 (d.f. 16) = 2.583; P<.02

D vs F t = 0.59; t.95 (d.f. 18) = 2.101; P>.05

NOTE that $\bar{E}$'s do not correspond to those in Table 3 due to variation of individual data.

The substrate from Point Steele beach contained 0.85% clay (Nickerson 1975). Nineteen clams were 1-year-old having a mean length ($\bar{X}$ ℓ.) = 12.1 ± 1.2 mm; 112 were 2 years old: $\bar{X}$ ℓ. = 31.9 ± 6.2 mm; and 4 were 3 years old: $\bar{X}$ ℓ. = 45.0 ± 2.6 mm. A chi-square test on the number of razor clams recovered from square A-C (see Table 5 for the frequencies) showed no difference in survival among plots after 1 year: X^2 = 2.21 (d.f. = 4), P = 70. Only two of the transplanted 1-year-old clams were recovered; one from A, and one from C.

Analysis of covariance of the penetrometer data (Table 6 gives mean pressures and penetrations) implied no difference in surface texture among the control and flushed plots of square D-F 1 year after treatment: F = 27.9 (d.f. = 2, 1), P = .13. Also, there were no scars; the plot areas blended smoothly with the surrounding substrate.

The reason that the submarginal plots were analyzed was that marginal and submarginal habitat types blend over short distances throughout the Copper River delta region. Hence, it was felt that a commercial harvester would either by chance or by choice (e.g., a rehabilitation program), be involved to some degree with submarginal habitat.

Clay levels remained essentially unchanged in control, vertically flushed, and horizontally flushed plots of square A-C when compared to their respective pre-treatment levels. Of interest is that although clay levels in horizontally flushed plots of square A-C increased a non-significant 24% (relatively large variances) from respective pre-treatment levels, the variability was considerably reduced; i.e., the substrate became more uniform. This increase is attributed to the greater flushing and mixing influence of horizontal flushing, which roils the substrate upward from a depth of 0.46 m. By contrast, vertical flushing roils downward and does not appear to penetrate effectively (with this model harvester) to a depth of 0.46 m.

Reflecting back on Reimnitz's (1966) studies of interbedding and cross-bedding of sand, silt, and clay, further interpretation of the results can be expanded. Clay layering may have been present below the level that core samples were obtained. Another possibility is that the substrate material at the site capping the edge of the clay-mud bank may have been shallow enough that the deepest jets caused incorporation of this lower material with the substrate above. This latter case appears to have been what happened.

Clay levels in control plots of square D-F increased significantly by 25% (relatively small variances), remained essentially unchanged in vertically flushed plots and decreased significantly by 18% in horizontally

Table 5. Number of razor clams recovered from plots in latin square A-C.

Row	A	B	C
I	6	5	7
II	8	9	4
III	5	5	3

Table 6. Mean pressure kg per plot (X) and mean penetration cm (Y) of substrate in latin square D-F.

Row	X Y	Column (Sample Size) 1	2	3
1		F1(8)	D1(8)	E1(8)
	X	17.1	20.6	18.0
	Y	15.0	13.5	14.6
2		D2(8)	E2(8)	F2(8)
	X	18.7	18.5	22.7
	Y	14.0	14.9	11.9
3		E3(8)	F3(8)	D3(8)
	X	21.8	22.5	22.2
	Y	14.6	11.7	9.5
Treatment		D	E	F
Means	X	20.5	19.4	20.8
	Y	12.3	14.7	12.9

flushed plots when compared to their respective pre-treatment levels. Post-treatment increase of clay levels in control plots of square D-F is attributed to time acting as a treatment. As previously mentioned, square D-F was located at the junction of two tidal channels. During flooding and ebbing tides an eddy is created in this area. The eddy effect may have influenced the increase of clay fractions. It is also possible that the immediate reduction of clay in vertically and horizontally flushed plots could have been more than core samples revealed 2 days after flushing. A 2-day waiting period was required because flushed plots were unapproachable as the substrate within and at the edge of the plots behaved like quicksand. It should be emphasized that there was no eddy effect at square A-C.

Results of vertically flushed plots in square D-F were essentially the same as those in square A-C. There was a slight but non-significant decrease in clay levels in these plots.

The significant decrease of clay levels in horizontally flushed plots of square D-F was as expected, though not below the 2.2% level. Thicker accumulation of surface sediments capping the edge of the mud-clay bank at square D-F at the confluence of the two tidal channels may have accounted for reduced clay fractions. If this situation occurred, then the lowest jets on the harvester did not contact or disturb the clay-mud profile below square D-F.

Results of the analysis of covariance obtained from square A-C, which implied no overall change in clay levels from "Before" to "After" flushing, correspond to the findings of Pfitzenmeyer (1966) who attributed no observable loss of fines to the very low silt-clay content and uniform nature of the sediments. Overall clay content of square A-C (1.56%) was relatively low compared to that of square D-F (3.34%). Horizontal flushing results from square D-F, in which reduced clay levels were in evidence following the treatment, correspond to the results of Haven (1970) who observed a 2.4% silt-clay content prior to dredging a test area and 0.6% silt-clay content after dredging.

The impact of larger commercial hydraulic harvesters (e.g., Hanks Harvester) may magnify our results considerably since these units use approximately 7570 ℓpm (2000 g.p.m.) within a pressure range of 3 to 23 kg/cm^2 (15 to 130 lbs./in.^{2}). Although our pressure was within this range, the discharge of water by the Hanks Harvester exceeds ours by 100 times. We recommend that management agencies examine deeply cored profiles (as deep as will be physically disturbed by hydraulic harvesters) of substrate where hydraulic harvesting is planned in order to assess potential changes in substrate composition. Management decisions based on deep core samples are suggested to determine whether the anticipated changes will either contribute to the improvement of the habitat for razor clams (no clay layers or clay-mud banks intercepted by coring) or whether they will contribute to the acceleration of habitat decline (clay layers or clay-mud banks intercepted repeatedly over short distances).

Results of the clam transplant indicated that extensive areas comprised of marginal habitat could be successfully reseeded following hydraulic harvesting by transplanting clams from optimal growing areas. This may also be possible with submarginal types after repeated flushing.

These results are consistent with those obtained by Jim Linsey (pers. comm., Director, Soils Laboratory, Alaska Department of Transportation, Valdez) after examining substrate samples from several razor clam beds (rated marginal) in the Cordova area. Lindsey reported:

> "...there is no cohesiveness as we would define the term. In fact, they are excellent examples of cohesionless material. With respect to the property of stability or load impact resistance, these materials have plenty of that as long as they are laying as they 'want to' with surface in equilibrium, so to speak, with the rhythmic forces of the ocean. Any abrupt forms these sands might accidentally take would not withstand the first rain let alone breakers, but once even with the surrounding surface this material should be the most stable of non-cemented fine grained masses".

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