An Evaluation and Management Considerations of the Use of A Hydraulic Escalator Clam Harvester on Intertidal Clam Populations in British Columbia

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AN EVALUATION AND MANAGEMENT CONSIDERATIONS OF THE USE OF A HYDRAULIC ESCALATOR CLAM HARVESTER ON INTERTIDAL CLAM POPULATIONS IN BRITISH COLUMBIA

BY

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Four clam beaches in a small area on the west coast of Vancouver Island were harvested by a hydraulic escalator clam harvester during the period November 1980 to April 1982. Following harvest five sites on three of the harvested beaches were sampled to assess changes in commercial clam stocks and physical changes to the beaches.

Total combined landings of littleneck, manila and butter clams by the harvester between 1980 and 1982 were approximately 75 t. Clam mortality associated with hydraulic harvest was estimated to be as great as the reported landings. Harvest resulted in deep trenches, mounds of side castings, a redistribution of substrate material and an overall instability of the beach surface.

British Columbia clam beaches are not ideally suited for hydraulic escalator clam harvesters and harvest in most areas will result in considerable and longlasting habitat disruption. Recovery of populations of littleneck, manila and butter clams to preharvest abundance is dependant on recruitment and a suitable habitat. Growth of clams to legal commercial size takes 3 to 5 years or more. The return of beach stability after harvest may require 3 to 4 years or longer. Guidelines for the use of mechanical clam harvesters are presented.

Key words: clams, hydraulic harvester, commercial fishing, management

RÉSUMÉ

De novembre 1980 à avril 1982, on a exploité quatre plages coquillières de'une petite région de la côte ouest de l'île Vancouver à l'aide d'une ramasseuse hydraulique à escalier roulant. Après la cueillette, on a échantillonné cinq emplacements à trois des plages exploitées afin d'évaluer les changements dans les stocks commerciaux de coquillages et les modifications physiques des plages.

Le total des débarquements de protothaca du Pacifique, de tapes japonais et de saxidomus lisse recueillis de 1980 à 1982, à l'aide de la ramasseuse, a atteint environ 75 t et la mortalité estimative des coquillages reliée à l'exploitation hydraulique a été aussi élevée. Cette exploitation a crée des fossés profonds, des monticules de terre, une redistribution du substrat et une instabilité générale de la surface de la plage.

Les plages coquillières de la Colombie-Britannique ne sont pas idéales pour les ramasseuses hydrauliques à escalier roulant, et l'exploitation dans la plupart des régions entrainera une perturbation profonde et durable de l'habitat. Le rétablissement des populations de protothaca du Pacifique, de tapes japonais et de saxidomus lisse à leur niveau d'abondance antérieure à l'exploitation dépend due recrutement et d'un habitat propice. Il faut de trois à cinq ans ou même plus avant que les coquillages atteignent une taille commerciale selon la Loi. Le rapport présente aussi des lignes directrices pour l'utilisation de ramasseuses mécaniques de coquillages.

Mots-cles: coquillages, ramasseuse hydraulique, pêche commerciale, gestion

INTRODUCTION

The objective of this study was to evaluate the operation of a hydraulic escalator clam harvester digging intertidal populations of butter clams, *Saxidomus giganteus*, littleneck clams, *Protothaca staminea*, and manila clams, *Tapes philippinarum*. An attempt was made to describe resulting biological changes to clam populations and physical changes to the beaches in a small area on the west coast of Vancouver Island.

HISTORY OF HYDRAULIC ESCALATOR CLAM HARVESTING IN BRITISH COLUMBIA

The hydraulic escalator clam harvester described in this study (Figure 1) is similar to the Hanks hydraulic harvester developed in 1951 for use in the soft shell clam industry on the Atlantic coast (Kyte et. al., 1975). Hydraulic escalator harvesters were introduced to the Pacific coast in 1956 where they were used to harvest hard and soft shell clams from intertidal and subtidal beaches in Puget Sound, Washington. At least one hydraulic escalator harvester has been in use in Puget Sound since then (Goodwin and Shaul, 1978).

Three hydraulic escalator harvesters have operated on a limited scale in British Columbia since 1964. The harvester assessed in this study was built and put into operation in 1974 and has worked sporadically on several beaches since then. Prior to 1980 reported clam landings from this harvester are unknown; however, in a 16 day period in 1975, the combined landings of littleneck, manila and butter clams from three beaches were 13 t. Between November, 1980 and April, 1982 combined annual landings of littleneck, manila and butter clams were 25 to 50 t for four to five weeks of harvest. Almost all these landings were from beaches within the study area.

OPERATION OF THE HYDRAULIC ESCALATOR HARVESTER

Described simply, the hydraulic escalator harvester assessed in this study consisted of a series of 23 one-half inch high pressure water jets on a 48 inch wide tilting hydraulic head, in front of a conveyor belt (Figure 2). The water jets acted to emulsify the bottom substrate and wash solid debris including clams onto the conveyor belt (Figure 3). Clams and other solid objects too large to fall through the mesh of the conveyor belt were carried to the surface where the legal size harvestable clams were removed (Figure 4). The minimum commercial size for littleneck and manila clams is 38 mm shell length and 63 mm for butter clams. Undersized and non-marketable clams along with debris are returned to the water over the end of the conveyor. The harvester is capable of digging intertidal or subtidal clams operating at water depths between 2 and 6 m. Beaches are normally worked until clam density is reduced to a point where clam harvest becomes unprofitable.

Kyte et. al. (1975) compared the impacts of a hydraulic escalator harvester and those of commercial hand digging on populations of soft shell clams, *Mya arenaria*, on the Atlantic coast. Generally for every 100 legal sized clams in an area, a hand digger removed 60 to 84. Among those left in the tract, including juveniles, 70 percent would die from breakage, from exposure or from smothering caused by burial. In contrast to hand digging, they found that the escalator harvester was suprisingly gentle with soft shell clams. Breakage was between 5 and 10 percent, but depended largely on the experience of the operator. Harvest efficiency and harvest mortality resulting from the escalator harvester was a function of the substrate firmness. Digging efficiency was as low as 11 percent in very firm substrate and as high as 100 percent in soft sandy substrate. Kyte et. al. (1975) found that a Hanks harvester could cover 10 to 60 times the ground in a given time compared to a hand digger. As well, they found that hydraulic harvesters required densities of clams much greater than did hand diggers to remain economically viable. In 1974, in the soft shell clam industry on the Atlantic coast, the minimum average clam density that a hydraulic harvester operator required to make a reasonable living was 2.5 to 3 times greater than the minimum density required by commercial hand diggers in the same area (Kyte et. al. 1975).

Unlike the large flat expansive clam beaches of sand and mud that hydraulic escalator harvesters were developed for on the Atlantic coast, British Columbia clam beaches are often small pockets of firm, coarse sub-strate with steep slopes and much rock and are in most cases not ideal for this type of harvester.

METHODS

During the period July, 1981 to April, 1982 we sampled a series of harvested and unharvested clam beaches in Mary and Inner Basins. Five sites were sampled on three clam beaches at the head of Nuchatlitz Inlet on the west coast of Vancouver Island (Figures 5 and 6). Site location was determined from harvest information and from projected harvest location.

An initial survey was conducted on a harvested beach at MB-1 (Figure 7), during July, 1981, four months after harvest. The purpose of this survey was to examine the obvious physical and biological changes to the beach resulting from harvest. This beach was sampled again during April, 1982, 12 to 16 months after harvest to determine if any recovery had occurred since initial harvest.

Four other sites, MB-2, MB-3, LC and IB-1 (Figures 7, 8 and 9) were sampled during October, 1981 and in April, 1982. The remoteness of these beaches and the period of harvest resulted in difficulties in co-ordinating sample site location with actual harvest site location. Only one site, IB-1 was sampled before and after harvest; sites MB-2 and LC were sampled only after harvest and site MB-3 was sampled, but never harvested.

At each site a series of 0.5 or 1.0 m^2 randomly located plots were sampled. Where harvesting had occurred, plots were dug both inside and outside of the harvested trenches. Each plot was dug to a depth of about 30 cm and all visible clams collected. No screening was done and clams less than 10 mm in shell height were probably missed in the samples. All the clams were sorted to species and individual lengths were recorded for littleneck, manila and butter clams to the nearest 1.0 mm. Weights were pooled according to legal and sublegal size categories and were recorded to the nearest 0.1 g.

Oblique aerial photographs were taken of the initially harvested beaches (Figure 10) in July, 1981 to estimate the extent of harvesting. Harvestable beach areas were determined by pacing and measuring off the areas where clams occurred and by comparing this to planimeter measurements of the beaches from hydrographic charts of the area.

RESULTS

PHYSICAL EFFECTS TO THE BEACH

Considerable disturbance to the beach surface was observed in areas where the hydraulic escalator harvester had worked. There were deep trenches criss-crossing the beach surface fromtchart datum to the upper limits of clam distribution (Figure 10); deep holes where the harvester had stopped forward motion while still digging (Figure 11); mounds of side cast material and rows of exposed empty shell lining the trenches (Figure 12) which were probably from accumulated empty shells buried in the substrate and not the result of a high harvest mortality. Observations made two to four months after harvest showed trenches that were more than 0.5 m deep and up to 2 m wide in most places. The side cast material from inside the trenches formed mounds more than 30 cm deep on either side of the trenches as well as on other parts of the original beach surface.

At site IB-1, which was a muddy estuarine beach, harvesting had caused much of the fine silt to be washed away and had changed the natural substrate composition to coarse sand. This beach was soft and unstable after harvest.

Twelve to sixteen months after harvest at site MB-1 trenching was still obvious, however, the trenches had begun to backfill and the mounds of side castings had started to level out. In many of the trenches there was a build up of fine organic material, 4 to 6 cm deep that was beginning to rot and leech into the surrounding substrate.

EFFECTS ON CLAM POPULATIONS

Most of the clams on the beaches were littlenecks and manilas, butter clams were present, but at lower densities at most locations, (Tables 1-5).

Four to six months prior to sampling site MB-1, in July, 1981, a combined weight of more than 25 t of littleneck, manila and butter clams were harvested from this beach. Mean weights per m^2 of these species from both in and out of the trenches at the time of sampling were 2.41, 0.23 and 0.62 kg/m^2 respectively.

Subsequent sampling of this same area during April, 1982, 12 to 16 months after harvesting, showed similar results. Mean weights per m^2 of littleneck, manila and butter clams from these samples were 2.40, 0.11 and 0.64 kg/m^2 respectively.

At site IB-1 which was sampled before and after harvest, total abundance of legal and sublegal size littleneck clams remained unchanged but the total abundance of legal and sublegal size manila clams declined significantly (Table 6).

At site MB-3 which was sampled but not harvested, there was a significant increase in abundance of littleneck clams between October, 1981 and April, 1982. Mean weight per square meter was 0.59 kg/m^2 in October, 1981 and 1.70 kg/m^2 in April, 1982. This increase in abundance was due to sampling error or recruitment to the sample size that occurred there but not in any of the harvested areas.

At sites MB-1 and LC which were harvested in 1981 but not 1982, there were no significant changes in abundance of any species fourteen to sixteen months after harvest.

Length frequency distributions for each species from each sample location are shown in figures 13 through 17. Except for littlenecks at site MB-3 there is little indication of recruitment to the sample size in any of these populations.

Clam mortality associated with hydraulic harvest was noted at sites IB-1 and MB-1 shortly after harvest. Rotting littleneck and manila clams were found at both sites, buried to depths of more than 30 cm in and beneath the side castings of the harvester (Figure 18). These clams probably died from smothering as littleneck and manila clams occur only to a maximum depth of 15 cm (Quayle and Bourne 1972).

Harvesting may also have caused mortalities through breakage and exposure, but this was not substantiated.

Although mortality associated with hydraulic harvest appeared to be substantial, we were unable to quantify it in terms of area harvested, However, the decline in standing stock of all species from all of the harvested beaches, from 1981 to 1982 (Table 7) was almost double the reported landings of 50 t of all species from the same period.

DISCUSSION

PHYSICAL EFFECTS TO THE BEACH

The most obvious effect caused by the hydraulic escalator harvester in this study was the physical disruption of the beach. There were deep trenches, holes, mounds of side cast materials, rows of exposed empty shells and unstable and unnatural conditions on the beach after harvest.

Clam harvesting by its very nature is disruptive. Hydraulic escalator harvesters, when used to harvest several species, tend to dig deeper, turn over more substrate and hence result in more habitat disruption than do hand diggers to harvest the same amount of clams.

Hydraulic escalator harvesters were originally developed on the Atlantic coast to dig clams on expansive flat subtidal areas of relatively soft uniform substrate. Escalator harvesters cause less physical disruption to these areas and they recover more rapidly to a stable condition than do typical British Columbia intertidal clam beaches which are small in size, relatively steep and composed of coarse, firm substrate (Quayle and Bourne 1972).

Studies in Puget Sound Washington (Goodwin et. al. 1978 and 1980) showed no obvious trenching immediately after harvest of a subtidal clam beach with a hydraulic escalator harvester but trenches and mounds of side cast material were observed two years after harvest of an intertidal clam beach.

The hydraulic escalator harvester discussed here was originally licenced to dig only subtidal clam stocks, however, it was allowed to dig intertidally when no commercial quantities of subtidal clams could be located.

In British Columbia no significant subtidal stocks of littleneck, manila or butter clams have been located and most areas havested by hydraulic escalator harvesters have been intertidal beaches. In most of these areas harvest caused a redistribution of the beach substrate materials and left unnatural and unstable conditions on the beach after harvest (unpublished data).

Habitat disruption in terms of the loss of beach stability, substrate movement and the changes in the natural vertical distribution of substrate materials are some of the most serious environmental impacts associated with hydraulic escalator clam harvesters. Goodwin et. al. (1980) noted that the loosening and emulsification, plus the loss of natural vertical stratification resulted in an increase in substrate movement in harvested clam beds and that many benthic organisms including clams would not colonize and grow in the substrate until stability returned.

The physical recovery of the beach depends on substrate composition, firmness and wave and tidal action. Mary and Inner Basin have intertidal, gravel beaches that are protected from direct wave exposure. These beaches may take three or more years to stabilize physically; substrate composition, however, may remain different for a much longer period of time.

MANAGEMENT CONCERNS

The escalator harvester is obviously most efficient when operating on ground for which it was designed. Operating this harvester on typical intertidal clam beds in British Columbia can result in considerable and long lasting habitat disruption which can cause increased mortality, reduced growth and loss of recruitment to clam stocks.

The hydraulic escalator harvester assessed in this study landed a combined weight of 50 t of littleneck, manila and butter clams from beaches in Mary and Inner Basins between November, 1981 and April, 1982. This was 12% of the total estimated standing stock of 1981 (Table 7) but harvesting during this period appeared to reduce stocks in most areas to unprofitable levels for the hydraulic harvester (personal communication operators of the hydraulic harvester).

As well as removing a large portion of the legal sized clams, harvesting caused considerable mortality in the remaining stocks. Table 7 shows the overall decline in standing stock of all species from 1981 to 1982 was in the order of 100 t; however, reported landings of clams from the same areas over this period were only 50 t. The decline in standing stock in excess of the reported landings may be indicative of incidental mortality during hydraulic harvesting. Clam harvesting that causes such a high mortality is clearly an inefficient use of the resource.

Recovery of clam populations after harvest is dependant on the survival of the sublegal clams in the harvested area and on successful recruitment. If considerable mortality of the sublegal population occurred as a result of breakage or smothering, recovery will be largely dependant on settlement and recruitment. In this instance, littleneck and manila clams attain the legal size in 3-4 years and butter clams in 5-6 years (Quayle and Bourne 1972). If there was successful recruitment immediately after harvest in Mary and Inner Basins, recovery of the stocks to preharvest levels would take at lease four to five years.

Our samples showed no significant recovery of any of the clam populations up to 16 months after harvest. Recruitment to the sample size was not evident in any of the harvested populations, so harvest may have resulted in significant mortality in the sublegal size classes. As a result recovery of these populations may be largely dependant on successful settlement and recruitment.

Recruitment is often erratic on British Columbia beaches and recovery could take longer than four or five years. Successful recruitment also depends on a suitable and stable physical environment. Trenching, mounds of side cast material, accumulation of organic debris in trenches and redistribution of beach material may produce an unsuitable environment for settlement and further delay the recovery of the clam populations.

The efficiency and rate of harvest of hydraulic escalator harvesters and the relatively small size of most of the British Columbia clam beaches makes it difficult to manage this type of operation on a sustained yield basis. If rotational harvesting was considered as an alternate management plan then several areas of a similar size and clam abundance as Mary and Inner Basins would be required to sustain a single hydraulic escalator harvester on an annual rotational basis.

Current policy requires that hydraulic clam harvesting only occurs in areas where there are no conflicts with historic commercial, sports or native hand digging operations, so the number of beaches currently available to hydraulic clam harvesting in any region of the coast appears to be limited. The extent of subtidal commercial clam populations in the 0 to 5 m depth range in British Columbia is not known.

Based on the results of this study, the hydraulic escalator harvester did not meet the mangement criterion for the acceptability of a mechanical harvester. (Appendix 1)

(1) sufficient areas of commercial clam abundance, intertidal (or subtidal) must be identified to operate on either a sustained yield or rotational basis.

(2) habitat disruption such as trenches, mounds of side cast materials, deep holes that lead to beach instability and accumulation of organic debris is not acceptable. Such events will affect survival, growth and recruitment of the clam stocks.

(3) mortality of both legal and sublegal clams by the operation of the harvester was as high as 100%. This incidental mortality is much greater than what occurs from hand digging. Harvest of clams by this method is not an efficient or acceptable use of the resource.

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APPENDIX

MANAGEMENT GUIDELINES FOR THE USE OF MECHANICAL HARVESTERS

Much of this section is from an unpublished report prepared by the Pacific Standing Committee on Shellfish (1975). The following guidelines should be considered before licening a mechanical clam harvester:

1. *Areas of commercial clam abundance must be identified*

Intertidal clam stocks: Current policy requires that hydraulic clam harvesting be carried out on a trial basis in areas where there are no conflicts with historic commercial, sports or native hand digging operations. As a consequence, the number of beaches currently available to hydraulic clam harvesting is limited.

Opportunities may exist to operate mechanical harvesters in contaminated areas closed due to paralytic shellfish poisoning (PSP) or unacceptable faecal bacteria levels. However, such activities must be strictly managed to assure that safe products are eventually marketed. Clams would have to be relayed to approved uncontaminated areas or taken to depuration plants.

Subtidal clam stocks: Although littleneck and butter clams have been found in depths up to 2 m no commercially harvestable populations have been found in waters of British Columbia by fishermen's exploration or surveys conducted by Fisheries and Oceans. There are, however, commercial subtidal stocks in nearby Puget Sound, Washington at depths to 5 m (Goodwin and Shaul 1978).

There are no migrations of clams between intertidal and subtidal clam populations. Neither butter nor littleneck clams move laterally on the beach once they are over 1 cm in shell length. It is not known whether subtidal clam populations make a significant contribution to the recruitment of intertidal clam stocks. Although clams present in the subtidal area would form part of the brood stock, removal of part of this population would not be expected to affect the success or failure of recruitment to either the intertidal or subtidal area.

2. *There must be a minimum of disruption to beach*

A desireable clam digger should return the substrate as close to its original position as possible. It should not leave trenches and bury areas which otherwise would not have been affected. Holes should not be formed from stopping or starting the digger hand.

A minimum habitat disruption will ensure the survival of sublegal size clams and protect those areas not harvested. It will also allow the area to be quickly repopulated by the clams and other burrowing or attached organisms which were originally present and comprised a balanced, biological community. The disruption of aquatic vegetation that may provide a substrate for herring spawn is an example of a serious concern.

3. *There must be a minimum of damage to both legal and sublegal size clams*

The operator should be encouraged to utilize as many of the clam species harvested as possible. The operating water pressures should not damage sublegal or legal size commercial clams.

(i) Sorting of the clams must be done on the spot and small (sublegal size) clams left in or returned to the substrate so that they can reestablish themselves.

(ii) breakage of species with brittle shells would be minimal.

(iii) there must be a minimum of substrate disruption (such as trenches and mounds) so that discarded clams are not smothered and areas that were not harvested are not buried.

4. *The design of the mechanical harvester must be approved*

To meet the previous criteria, the design of the harvester must be approved. Sketches and blueprints and operating specifications are required. Of particular interest are such details as operating and maximum water pressures, maximum manifold width, and the spacing of nozzles. While we support innovation, there are certain concepts and criteria to be taken into account which will ultimately decide whether any new types of diggers will or will not be accepted by the Department.

TABLE 1. Summaries of mean total and mean legal densities and weights of littleneck, manila and butter clams at all sites.

		LITTLENECKS				MANILAS				BUTTERS			
		Total		Legal		Total		Legal		Total		Legal	
Site	Date	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2
IB-1	October, 1981	148.7	1.68	40.66	0.78	268.0	4.11	174.0	3.37	0.00	0.00	0.00	0.00
IB-1	April, 1982	216.3	3.74	108.3	2.65	83.33	1.88	75.00	1.74	0.33	0.01	0.00	0.00
LC	October, 1981	65.71	1.27	31.14	0.96	30.00	0.08	24.00	0.72	4.68	0.18	1.43	0.12
LC	April, 1982	144.2	1.72	47.33	0.97	21.33	0.31	10.67	0.25	1.33	0.08	0.67	0.04
MB-1	July, 1981	108.1	2.41	71.86	2.02	14.00	0.23	10.00	0.19	14.00	0.62	2.80	0.20
MB-1	April, 1982	142.0	2.40	61.11	1.54	6.22	0.11	5.56	0.11	25.11	0.64	5.78	0.14
MB-2	April, 1982	172.9	2.84	77.78	1.68	8.44	0.12	5.11	0.09	13.11	0.57	5.22	0.35
MB-3	October, 1981	45.75	0.59	8.75	0.27	19.50	0.23	6.75	0.13	0.25	0.03	0.00	0.00
MB-3	April, 1982	77.60	1.70	43.20	1.35	0.00	0.00	0.00	0.00	15.60	0.93	6.80	0.75

TABLE 2. Number and weights of clams per square metre at Mary Basin Beach; site MB-1 and MB-3, July and October, 1981.

		LITTLENECKS				MANILAS				BUTTERS			
		Total		Legal		Total		Legal		Total		Legal	
Site	Plot #	$\#/m^2$	kg/m^2	$\#/m^2$	kg/m^2	$\#/m^2$	kg/m^2	$\#/m^2$	kg/m^2	$\#/m^2$	kg/m^2	$\#/m^2$	kg/m^2
	1	26	0.93	24	0.92	0	0.00	0	0.00	0	0.00	0	0.00
	2	214	6.13	184	5.82	0	0.00	0	0.00	0	0.00	0	0.00
MB-1	3	82	1.98	57	1.73	0	0.00	0	0.00	8	0.40	2	0.14
July, 1981	4	12	0.18	3	0.05	0	0.00	0	0.00	0	0.00	0	0.00
	5	44	1.24	37	1.19	0	0.00	0	0.00	0	0.00	0	0.00
	6	158	3.90	126	3.57	0	0.00	0	0.00	24	1.08	6	0.46
	7	78	2.39	70	2.30	0	0.00	0	0.00	16	0.65	4	0.28
	8	60	2.03	56	1.99	0	0.00	0	0.00	0	0.00	0	0.00
	9	244	6.03	204	5.75	2	0.04	2	0.04	14	0.92	10	0.71
	10	136	3.52	120	3.33	0	0.00	0	0.00	23	1.47	15	1.14
	11	96	1.04	18	0.29	30	0.62	18	0.56	2	0.07	0	0.00
	12	274	3.68	94	1.80	156	2.42	116	2.03	2	0.07	0	0.00
	13	83	1.50	47	1.11	0	0.00	0	0.00	108	4.63	5	0.30
	14	7	0.06	0	0.00	1	0.02	1	0.02	0	0.00	0	0.00
	15	107	1.56	28	0.47	21	0.31	13	0.24	0	0.00	0	0.00
	Σ	1621	36.17	1078	30.32	210	3.41	150	2.89	210	9.29	42	3.03
	$\overline{X}$	108.1	2.41	71.86	2.02	14.00	0.23	10.00	0.19	14.00	0.62	2.80	0.20
	s^2	6346	3.32	3857	3.25	1516	0.37	8303	0.26	701.5	1.36	19.23	0.11
	1	0	0.00	0	0.00	18	0.16	0	0.00	0	0.00	0	0.00
	2	186	1.72	16	0.33	68	0.94	44	0.75	0	0.00	0	0.00
MB-3	3	26	0.24	0	0.00	20	0.22	6	0.11	0	0.00	0	0.00
October,	4	40	0.40	4	0.08	20	0.13	0	0.00	0	0.00	0	0.00
1981	5	32	0.87	16	0.68	0	0.00	0	0.00	0	0.00	0	0.00
	6	4	0.05	0	0.00	4	0.03	0	0.00	0	0.00	0	0.00
	7	40	0.50	12	0.27	22	0.19	0	0.00	0	0.00	0	0.00
	8	38	0.91	22	0.76	4	0.14	4	0.14	2	0.18	0	0.00
	Σ	366	4.69	70	2.12	156	1.81	54	1.00	2	0.18	0	0.00
	$\overline{X}$	45.75	0.59	8.75	0.27	19.50	0.23	6.75	0.13	0.25	0.03	0.00	0.00
	s^2	3026	0.28	67.93	0.08	402.8	0.08	202.9	0.06	0.44	0.00	0.00	0.00
	Σ	1987	40.86	1148	32.44	366	5.22	204	3.89	199	9.66	42	3.05
TOTAL	$\overline{X}$	86.39	1.78	49.91	1.41	15.91	0.23	8.87	0.17	8.65	0.42	1.83	0.13
	s^2	6075	3.02	3442	2.85	1136	0.27	614.5	0.19	503.3	0.92	14.31	0.08

Σ = Total number or total weight of clams sampled.

$\overline{X}$ = Mean number or weight of clams per square metre of beach surface.

s^2 = Variance.

TABLE 3. Numbers and weights of clams per square metre at Mary Basin Beach; sites MB-1, MB-2 and MB-3, April, 1982.

Site	Plot #	LITTLENECKS				MANILAS				BUTTERS			
		Total		Legal		Total		Legal		Total		Legal	
		$\#/m^2$	kg/m^2	$\#/m^2$	kg/m^2	$\#/m^2$	kg/m^2	$\#/m^2$	kg/m^2	$\#/m^2$	kg/m^2	$\#/m^2$	kg/m^2
MB-1	1	76	1.00	18	0.39	0	0.00	0	0.00	70	0.94	0	0.00
	2	160	1.72	24	0.54	2	0.01	0	0.00	54	0.60	0	0.00
April,	3	110	3.20	92	3.06	0	0.00	0	0.00	34	1.18	8	0.44
	4	10	0.14	4	0.09	0	0.00	0	0.00	0	0.00	0	0.00
1982	5	272	4.68	152	3.52	2	0.02	0	0.00	32	1.24	28	0.32
	6	24	0.52	18	0.45	0	0.00	0	0.00	32	1.66	16	0.51
	7	142	3.52	108	3.17	0	0.00	0	0.00	4	0.14	0	0.00
	8	160	2.48	60	1.26	18	0.38	16	0.35	0	0.00	0	0.00
	9	324	4.38	74	1.35	34	0.62	34	0.62	0	0.00	0	0.00
	Σ	1278	21.64	550	13.83	56	9.27	50	0.97	226	5.76	52	1.27
	$\bar{x}$	142	2.40	61.11	1.54	6.22	0.11	5.56	0.11	25.11	0.64	5.78	0.14
	s^2	9711	2.45	2215	1.62	126.6	0.05	126.0	0.04	595.7	0.36	89.28	0.04
MB-2	1	0	0.00	0	0.00	0	0.00	0	0.00	4	0.02	0	0.00
	2	278	4.56	140	3.43	4	0.02	0	0.00	32	0.88	8	0.64
April,	3	80	1.30	40	0.84	8	0.10	4	0.06	0	0.00	0	0.00
	4	66	1.04	36	0.77	0	0.00	0	0.00	50	2.64	22	1.87
1982	5	276	4.84	138	3.08	0	0.00	0	0.00	24	1.12	4	0.39
	6	176	2.94	70	1.51	0	0.00	0	0.00	8	0.44	4	0.28
	7	28	0.28	4	0.06	4	0.04	0	0.00	0	0.00	0	0.00
	8	192	3.00	84	1.71	16	0.16	4	0.08	0	0.00	0	0.00
	9	460	7.56	188	3.74	44	0.78	38	0.71	0	0.00	0	0.00
	Σ	1556	25.52	700	15.14	76	1.10	46	0.85	118	5.10	38	3.18
	$\bar{x}$	172.9	2.84	77.78	1.68	8.44	0.12	5.11	0.09	13.11	0.57	5.22	0.35
	s^2	19491	5.50	3824	1.80	182.9	0.06	137.9	0.05	292.5	0.70	46.62	0.33
MB-3	1	56	1.12	28	1.03	0	0.00	0	0.00	6	0.28	2	0.27
	2	114	1.56	44	0.67	0	0.00	0	0.00	0	0.00	0	0.00
April,	3	114	2.14	54	1.50	0	0.00	0	0.00	14	0.68	6	0.52
	4	56	1.68	46	1.57	0	0.00	0	0.00	28	1.34	8	0.91
1982	5	48	2.00	44	1.96	0	0.00	0	0.00	30	2.36	18	2.05
	Σ	388	8.50	216	6.73	0	0.00	0	0.00	78	4.66	34	3.75
	$\bar{x}$	77.6	1.70	43.2	1.35	0.00	0.00	0.00	0.00	15.60	0.93	6.80	0.75
	s^2	891.8	0.13	71.36	0.20	0.00	0.00	0.00	0.00	139.8	0.71	39.36	0.51
TOTAL	Σ	3222	55.66	1466	35.70	132	2.10	92.00	1.82	422	15.52	124	8.20
	$\bar{x}$	140.1	2.42	63.74	1.55	5.72	0.09	4.00	0.08	18.35	0.67	5.39	0.36
	s^2	12892	3.32	2550	1.40	131.2	0.04	98.43	0.04	408.2	0.59	62.76	0.31

TABLE 4. Numbers and weights of clams per square metre at Laurie Creek; site LC, October, 1981 and April, 1982.

		LITTLENECKS				MANILAS				BUTTERS			
		Total		Legal		Total		Legal		Total		Legal	
Site	Plot #	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2
LC	1	60	0.76	4	0.86	66	1.74	58	1.66	0	0.00	0	0.00
	2	84	1.61	46	1.09	48	1.28	46	1.23	4	0.35	4	0.35
October,	3	40	0.99	34	0.90	4	0.09	2	0.07	6	0.27	2	0.19
1981	4	62	1.06	28	0.71	6	0.11	4	0.08	6	0.06	0	0.00
	5	106	2.91	80	2.62	0	0.00	0	0.00	18	0.55	4	0.27
	6	0	0.00	0	0.00	2	0.08	2	0.08	0	0.00	0	0.00
	7	108	1.58	26	0.56	84	2.28	56	1.96	0	0.00	0	0.00
	Σ	460	8.91	218	6.74	210	5.58	162	5.08	34	1.23	10	0.81
	$\bar{X}$	65.71	1.27	31.14	0.96	30.00	0.08	24	0.72	4.86	0.18	1.43	0.12
	s^2	1253	0.70	622.7	0.56	1067	0.77	658.3	0.63	35.28	0.04	3.10	0.02
LC	1	66	1.39	46	1.14	12	0.23	8	0.20	0	0.00	0	0.00
April,	2	62	0.97	30	0.66	10	0.20	10	0.20	62	0.11	0	0.00
1982	3	216	2.79	66	1.10	42	0.49	14	0.35	2	0.12	2	0.12
	Σ	344	5.15	142	2.90	74	0.92	32	0.75	4	0.23	2	0.12
	$\bar{X}$	144.7	1.72	47.33	0.97	21.33	0.31	10.67	0.25	1.33	0.08	0.67	0.04
	s^2	5136	0.61	216.9	0.05	214.2	0.02	6.22	0.01	0.88	0.00	0.89	0.00

TABLE 5. Numbers and weights of clams per square metre at Inner Basin Beach; site IB-1, October, 1981 and April, 1982.

		LITTLENECKS				MANILAS				BUTTERS			
		Total		Legal		Total		Legal		Total		Legal	
Site	Plot #	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2	#/m^2	kg/m^2
IB-1	1	194	2.25	58	1.12	304	3.84	148	2.42	0	0.00	0	0.00
October,	2	220	2.44	56	1.05	266	4.64	186	3.87	0	0.00	0	0.00
1981	3	32	0.35	8	0.17	234	3.84	188	3.83	0	0.00	0	0.00
	Σ	446	5.04	122	2.34	804	12.32	522	10.12	0	0.00	0	0.00
	$\bar{X}$	148.7	1.68	40.66	0.78	268.0	4.11	174.0	3.37	0	0.00	0	0.00
	s^2	1918	0.89	534.2	0.17	818.7	0.14	338.7	0.45	0	0.00	0	0.00
IB-1	1	250	2.88	66	1.37	48	0.64	24	0.38	2	0.02	0	0.00
	2	98	1.56	48	1.10	14	1.92	10	1.50	0	0.00	0	0.00
April,	3	124	1.60	46	0.96	24	0.46	22	0.42	0	0.00	0	0.00
1982	4	56	0.88	38	0.64	12	0.38	12	0.37	0	0.00	0	0.00
	5	140	2.72	66	1.58	24	0.30	14	0.24	0	0.00	0	0.00
	6	630	12.84	386	10.26	378	7.60	368	7.52	0	0.00	0	0.00
	Σ	1298	22.46	650	95.46	500	11.3	450	10.43	2	0.02	0	0.00
	$\bar{X}$	216.3	3.74	108.3	2.65	83.33	1.88	75.00	1.74	0.33	0.003	0	0.00
	s^2	37719	17.02	15526	11.66	17502	6.84	17196	6.86	0.56	0.00	0	0.00

TABLE 6. Total and legal abundance (kg/m^2) of littleneck and manila clams at Site IB-1 before and after harvest.

Species	Before Harvest Total	Before Harvest Legal	After Harvest Total	After Harvest Legal
LITTLENECKS				
kg/m^2	1.68	0.78	1.92	1.13
variance	0.89	0.17	0.57	0.11
MANILAS				
kg/m^2	4.11	3.37	0.74	0.58
variance	0.14	0.45	0.36	0.21
COMBINED				
kg/m^2	5.78	4.15	2.67	1.71
variance	1.44	0.42	0.77	0.28

TABLE 7. Standing stock estimates for harvested beaches.

Site	Species	Standing Stock Estimates ± 95% Confidence Intervals 1981	1982
1. Mary Basin	LN	142,000 ± 56,528	193,600 ± 59,275
MB-1, MB-2, MB-3	M	18,400 ± 16,902	7,408 ± 6,707
	B	33,600 ± 25,612	53,982 ± 24,990
2. Laurie Creek	LN	63,500 ± 30,832	86,000 ± 43,965
LC	M	40,000 ± 32,337	15,333 ± 7,330
	B	9,000 ± 7,370	4,000 ± 3,060
3. Inner Basin	LN	84,000 ± 53,105	96,000 ± 32,919
IB	M	205,500 ± 21,229	37,000 ± 26,161
TOTAL	All Species	597,800 ± 243,915	493,323 ± 204,407

LN = littleneck clams

M = manila clams

B = butter clams

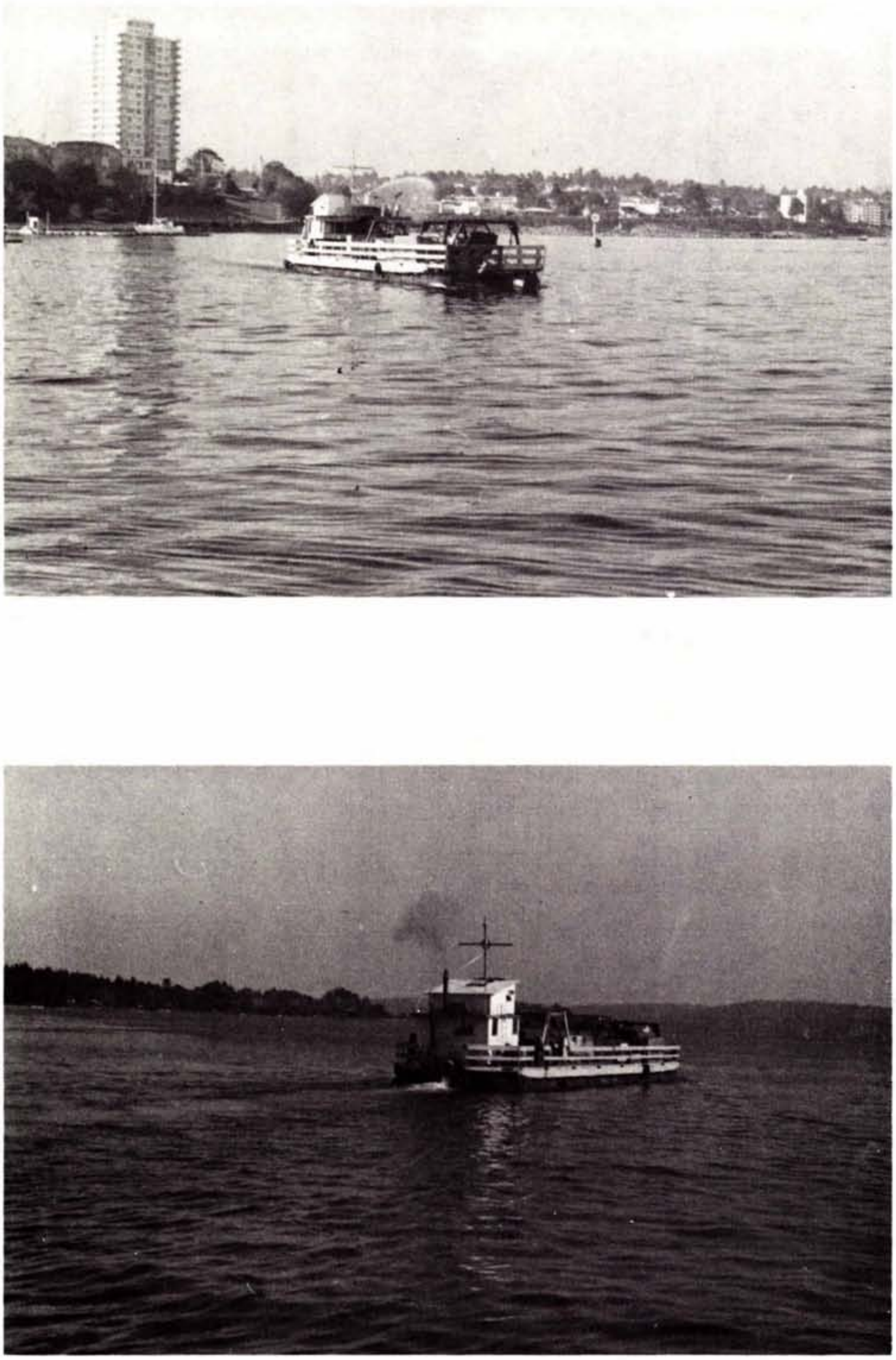


FIGURE 1. The hydraulic escalator harvester.

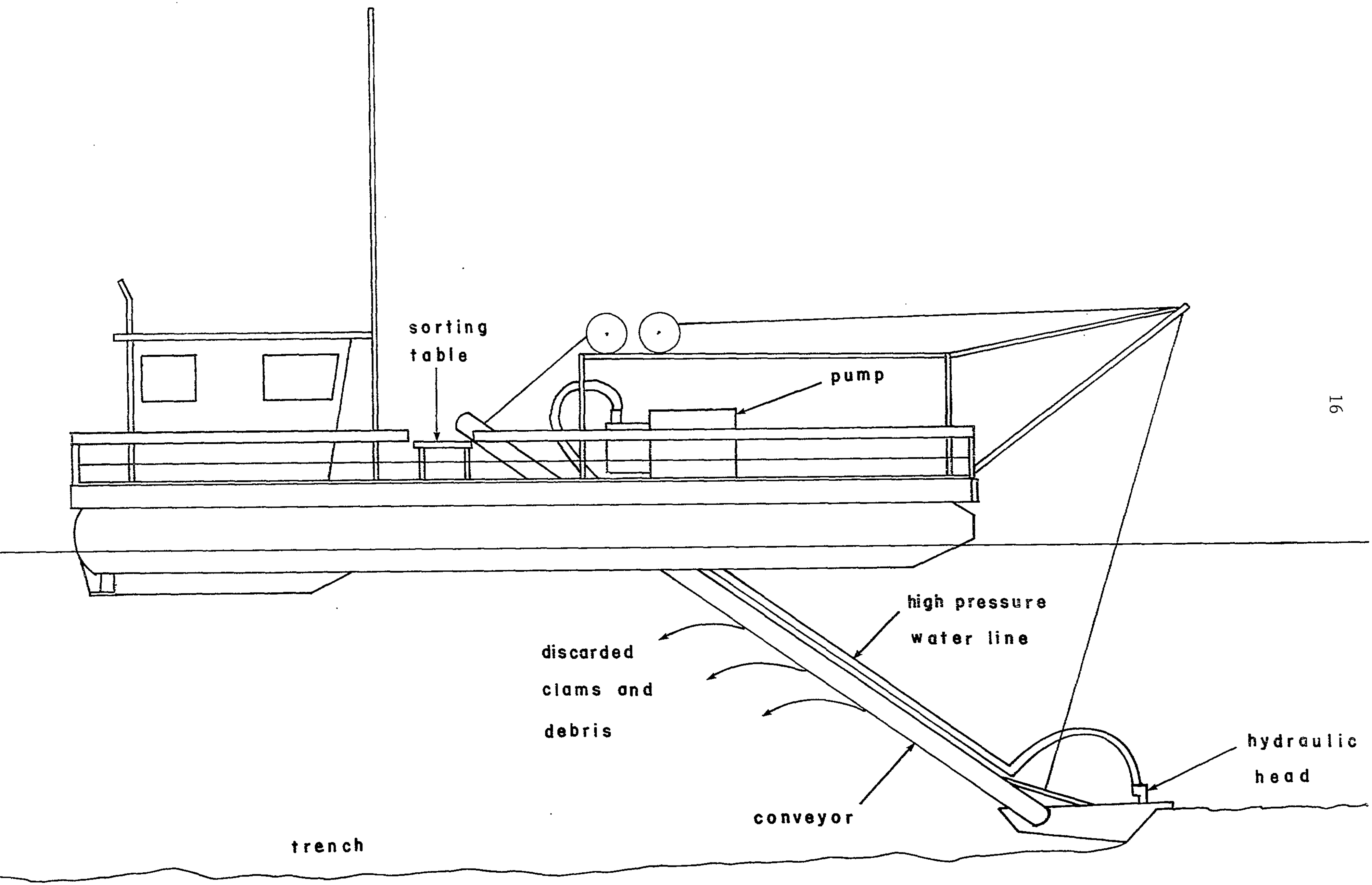


FIGURE 2. Details of the clam harvester

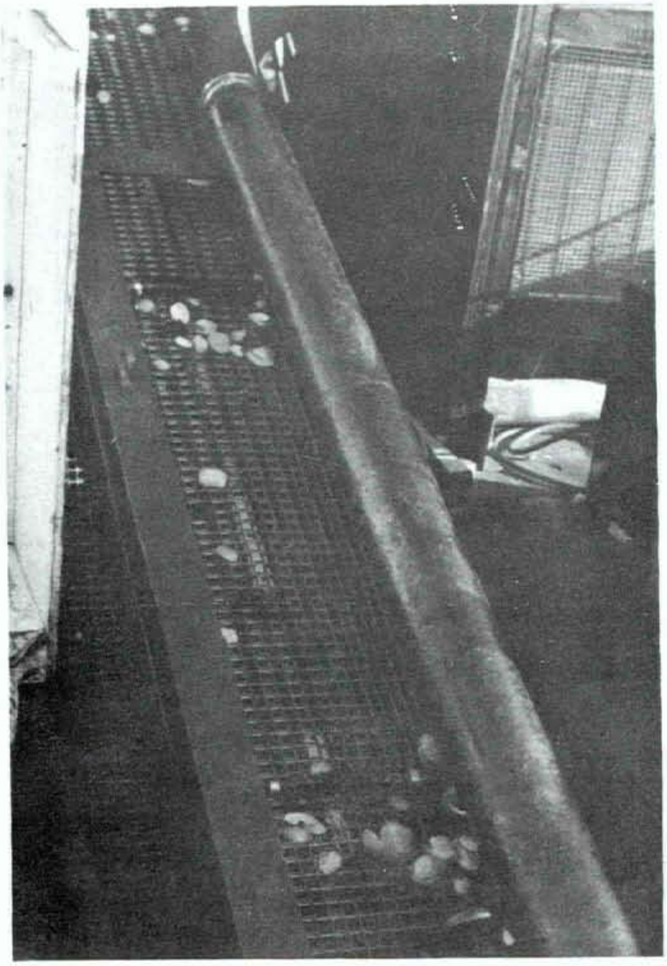


FIGURE 3. Harvested clams on the conveyor belt.

FIGURE 4. Sorting clams for legal sized marketable species.

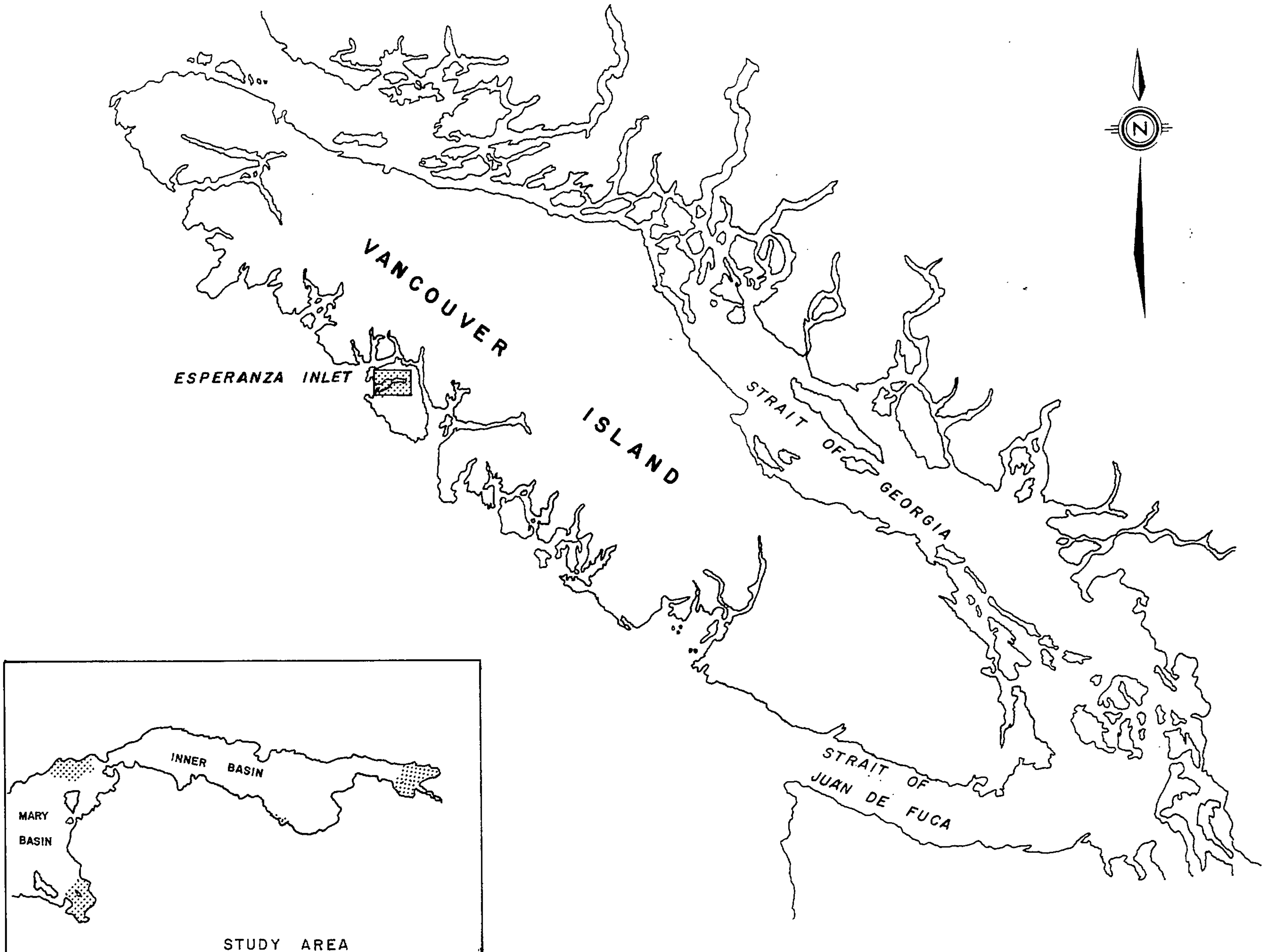


FIGURE 5. Location of study area.

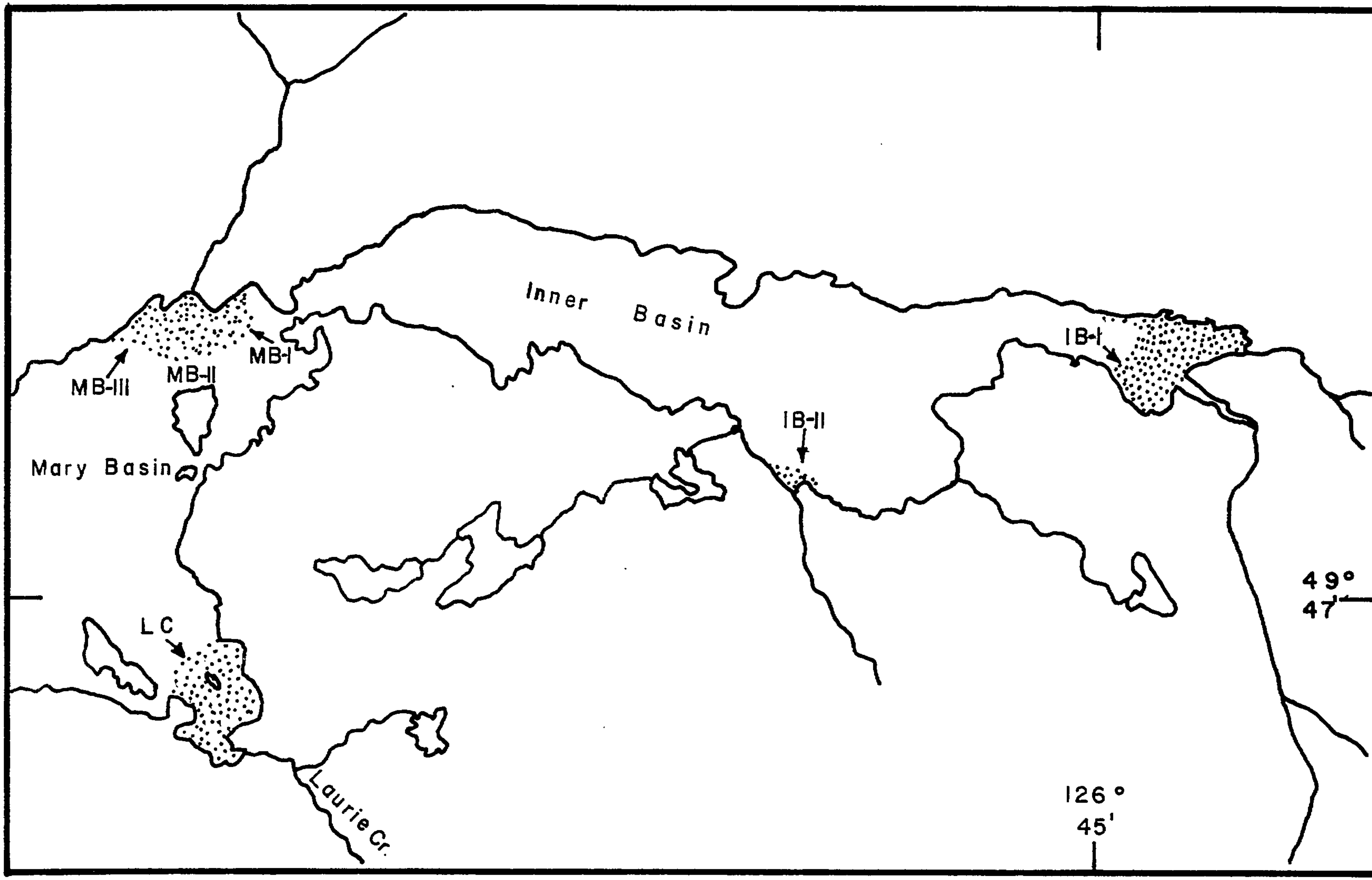


FIGURE 6. Location of sample sites.

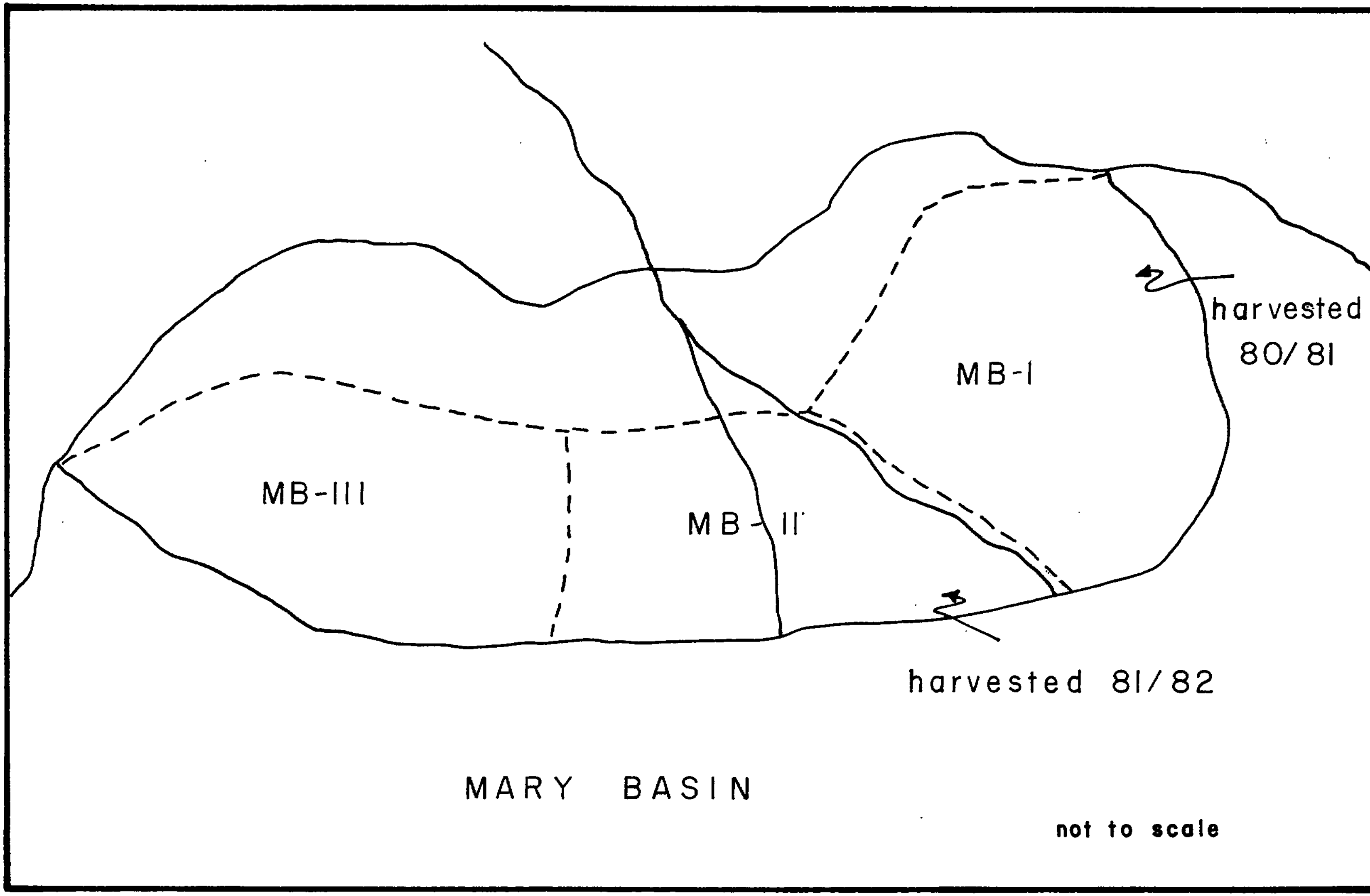


FIGURE 7. Sample sites MB-1, MB-2 and MB-3.

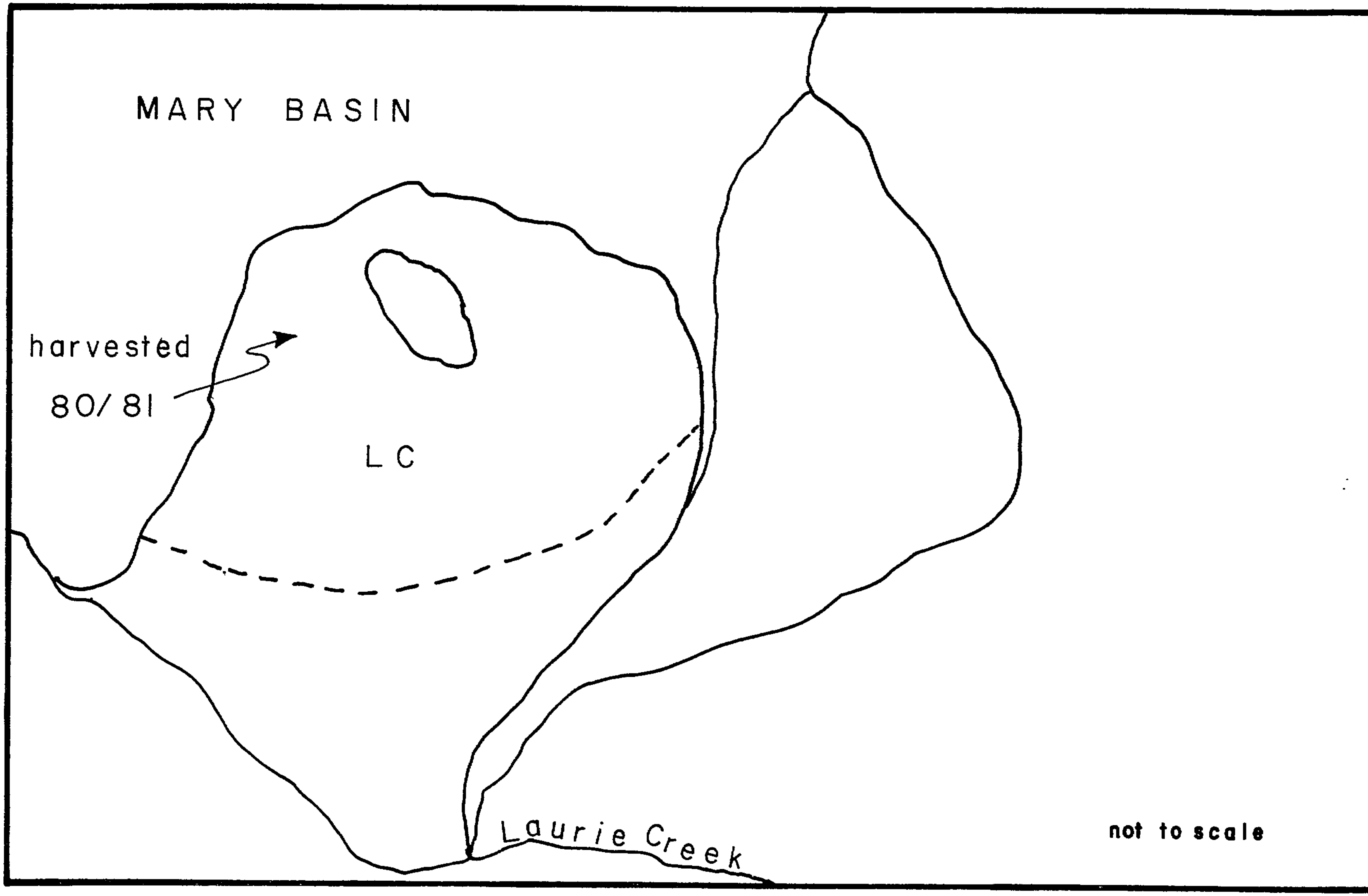


FIGURE 8. Sample site LC at Laurie Creek.

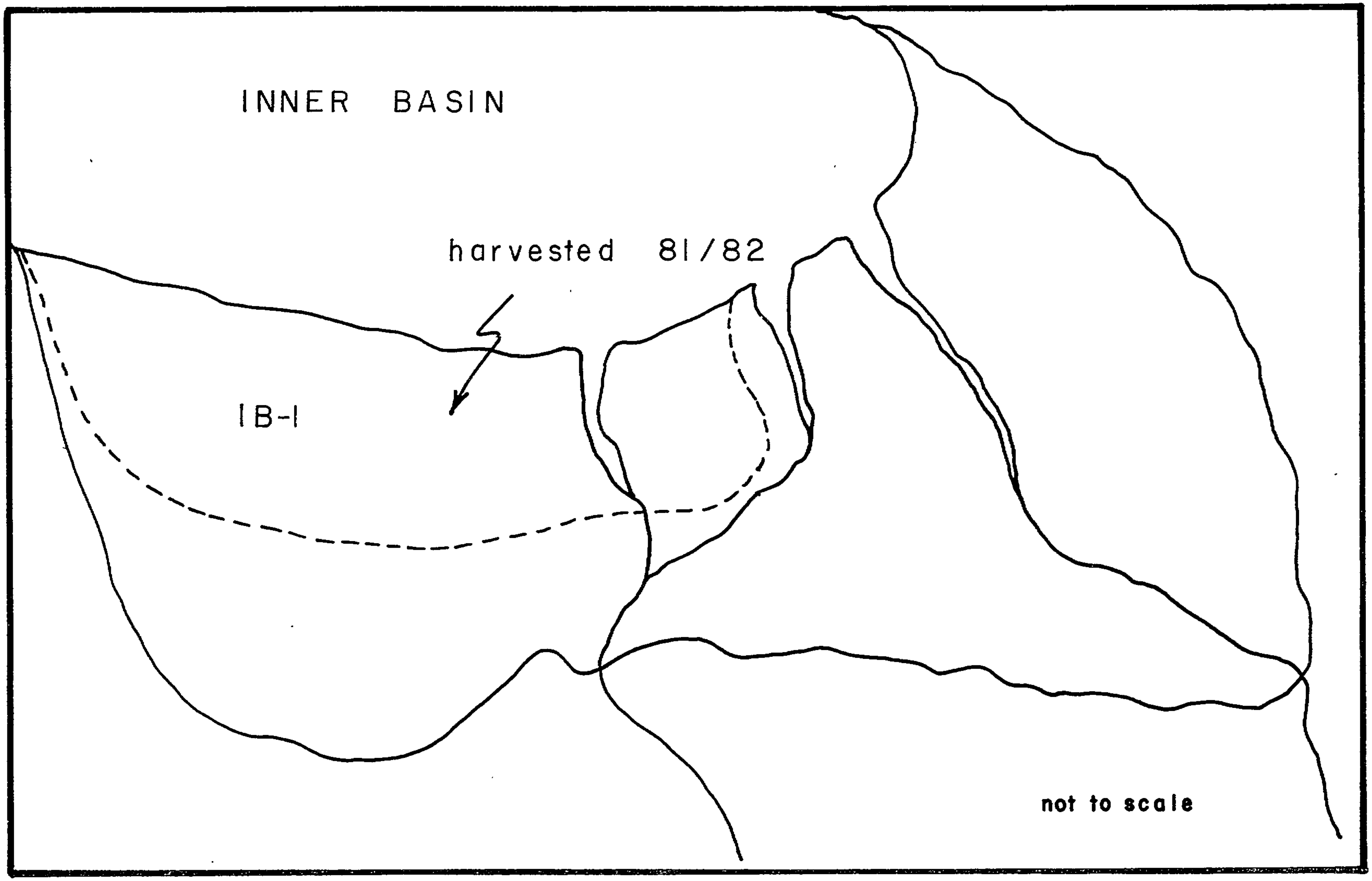


FIGURE 9. Sample site IB-1.

FIGURE 10. Aerial p'.otographs of site MB-1 illustrating trenches result'.ng from hydraulic harvesting.

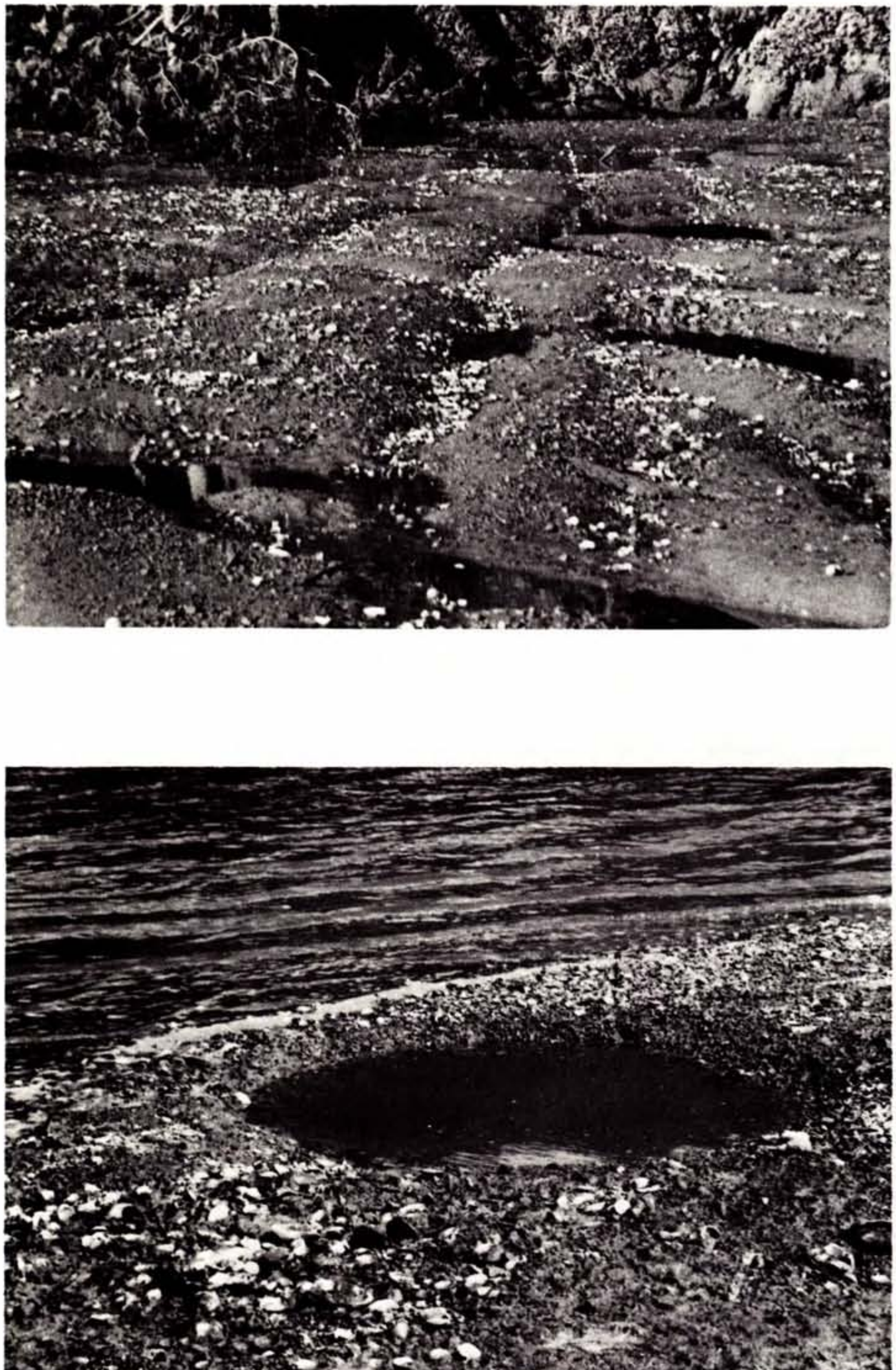


FIGURE 11. Site IB-1 one month after harvest.

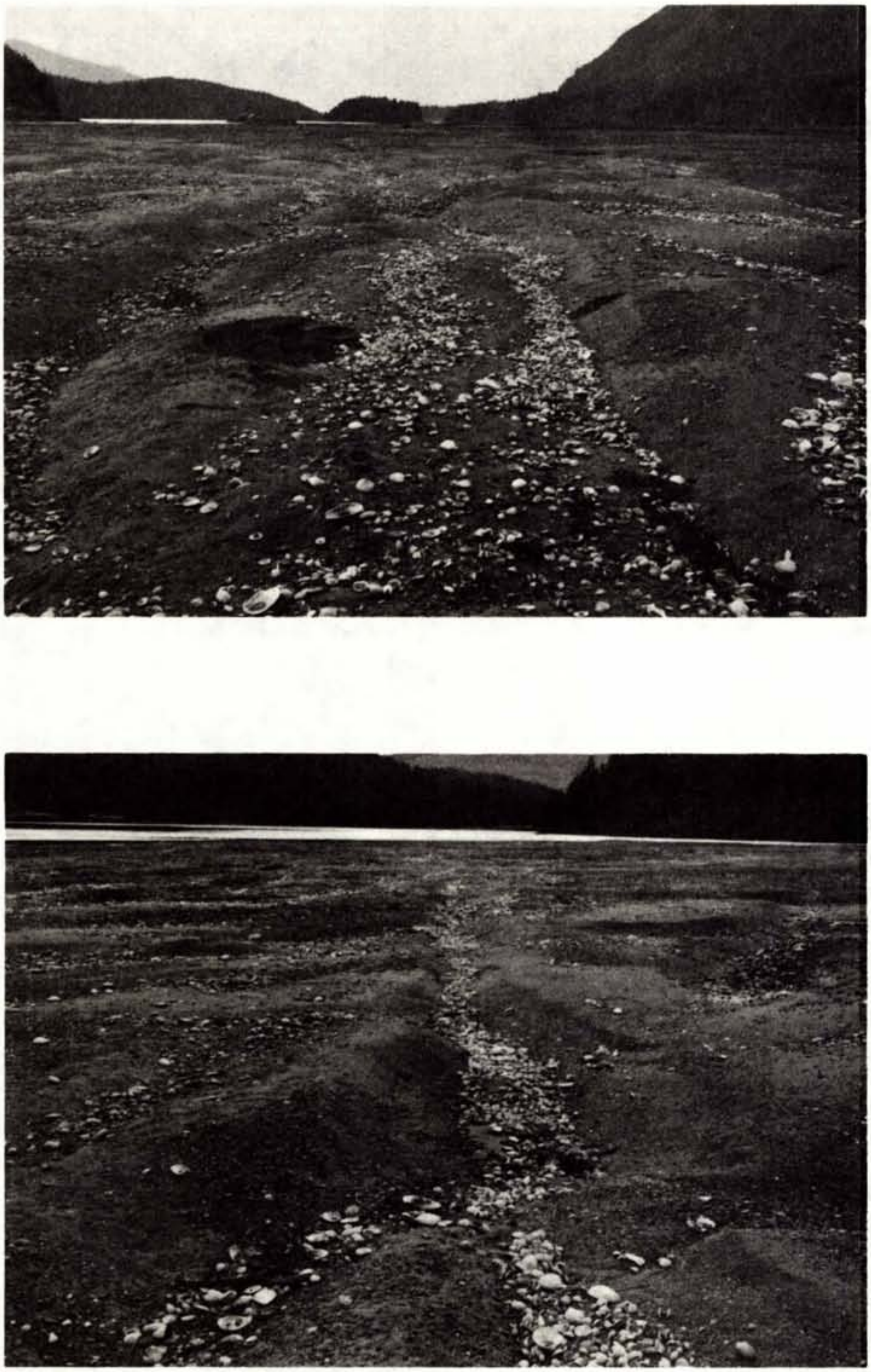


FIGURE 12. Site MB-1 four months after harvest.

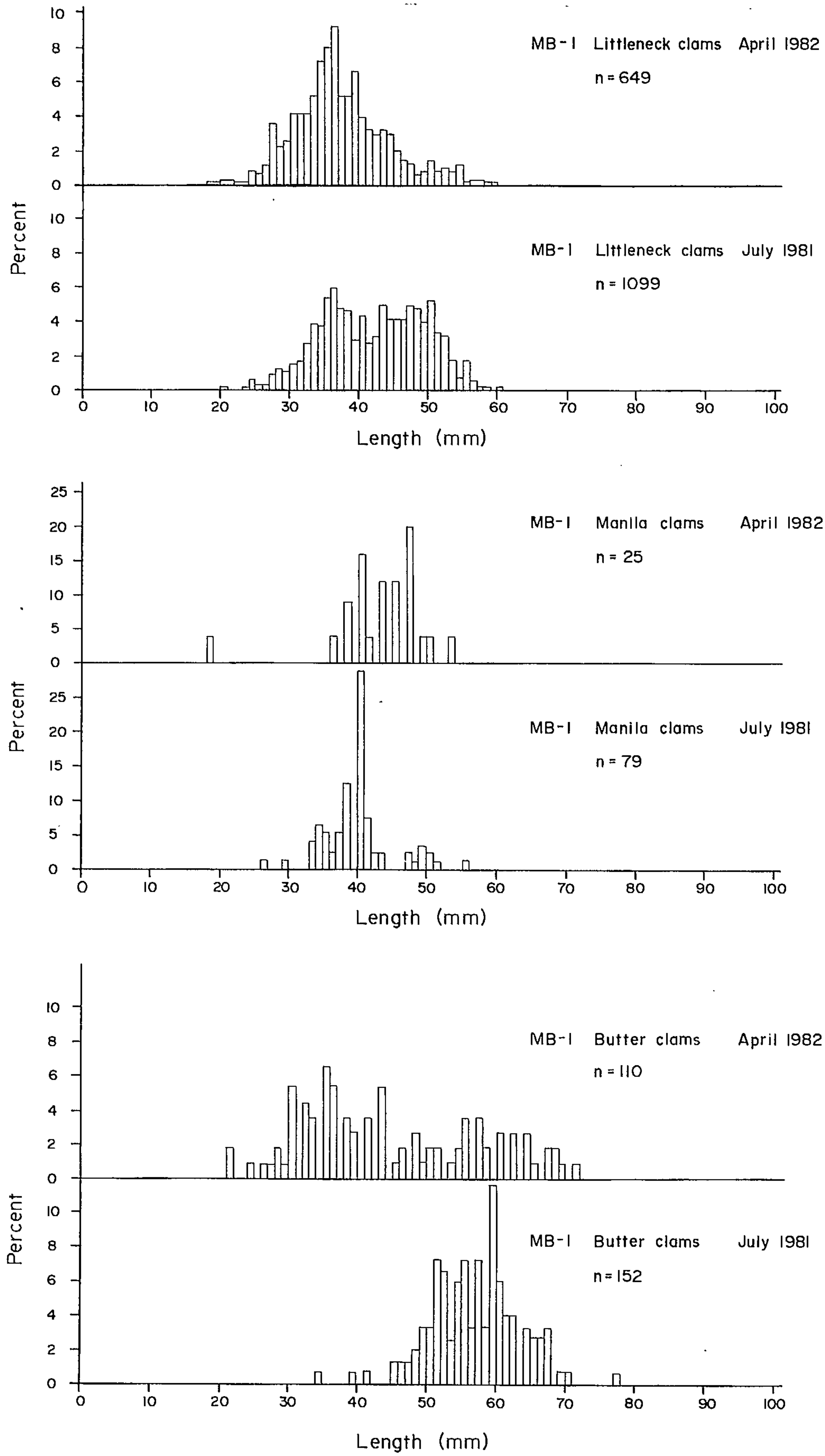


FIGURE 13. Length frequency histograms of littleneck, manila and butter clams from samples taken during July, 1981 and April, 1982 at site MB-1.

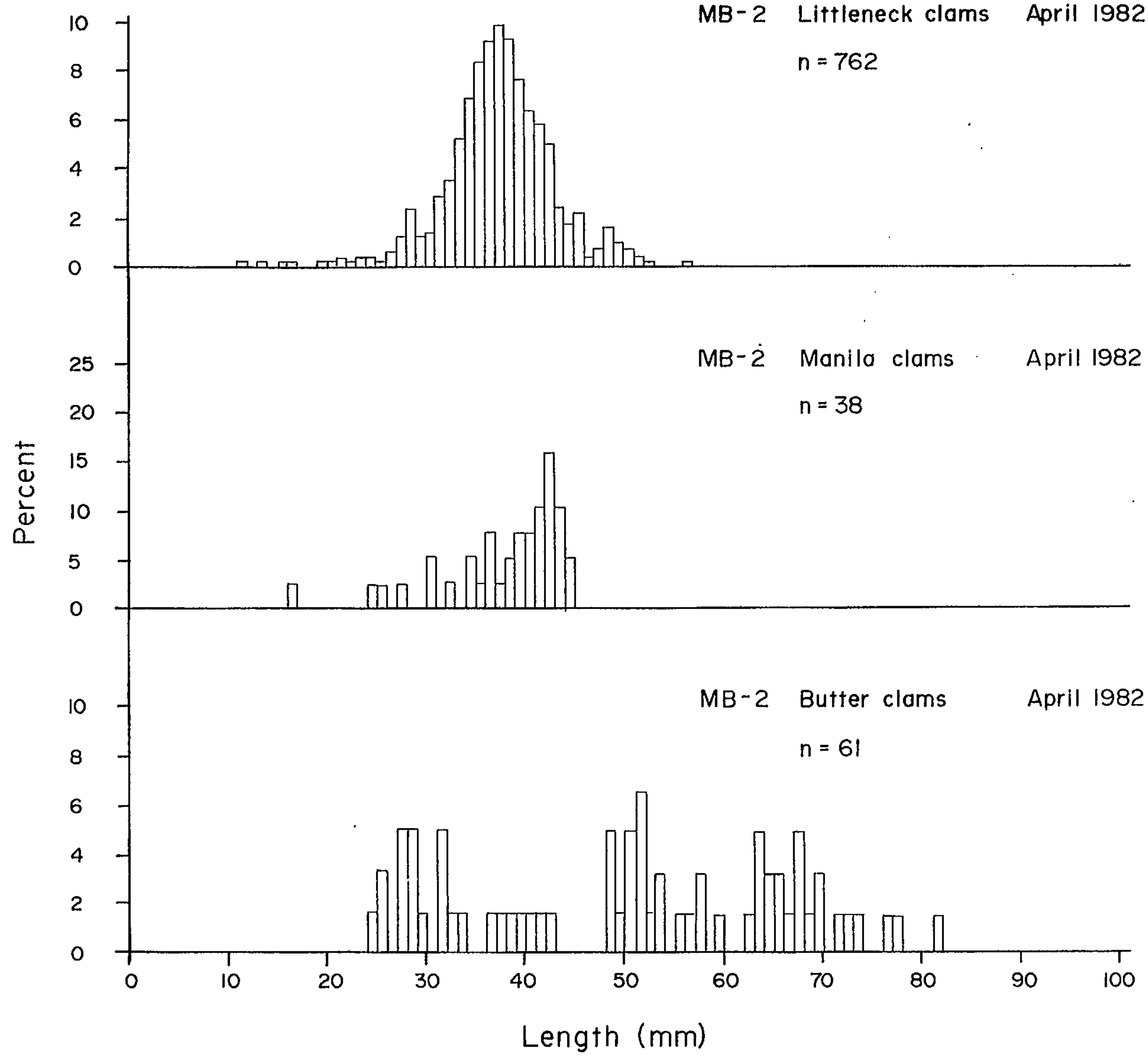
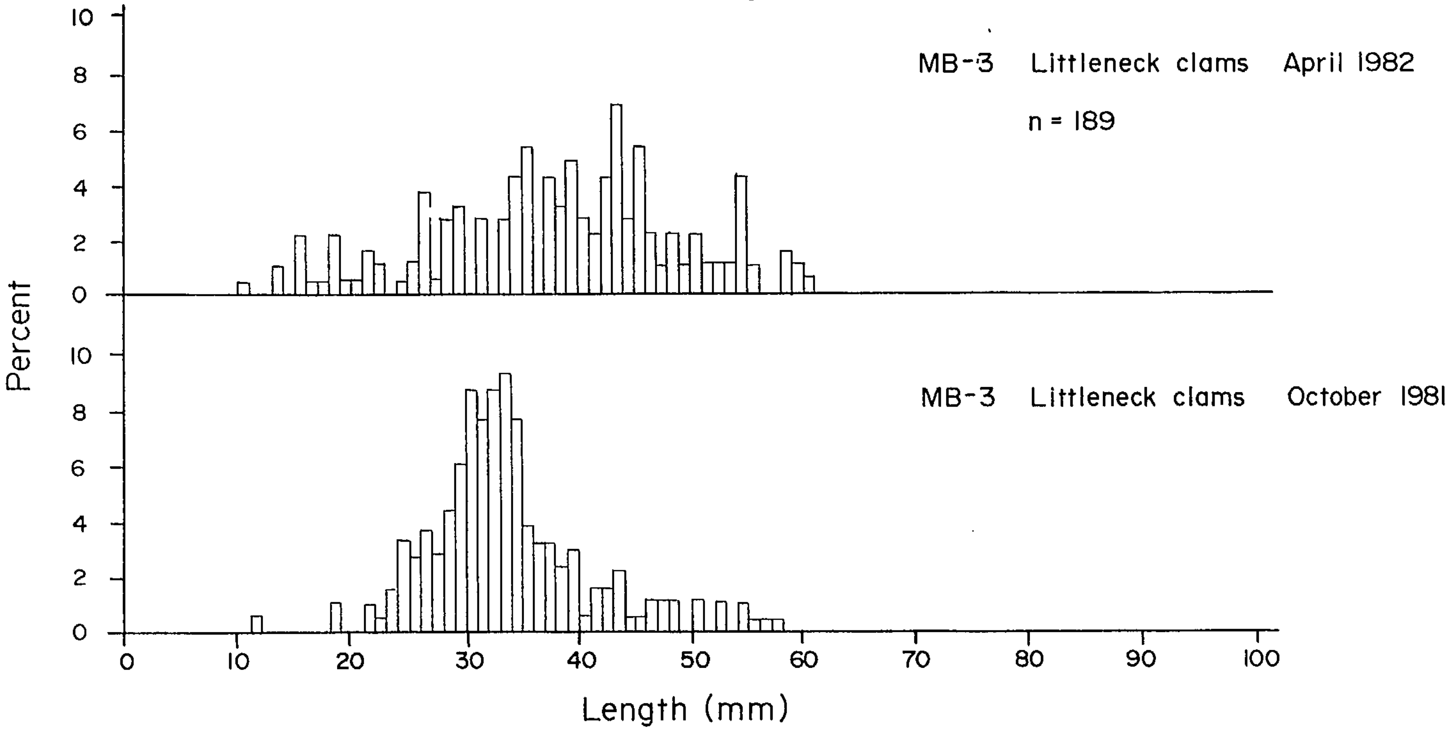


FIGURE 14. Length frequency histograms of littleneck, manila and butter clams from samples taken during April, 1981 at site MB-2.



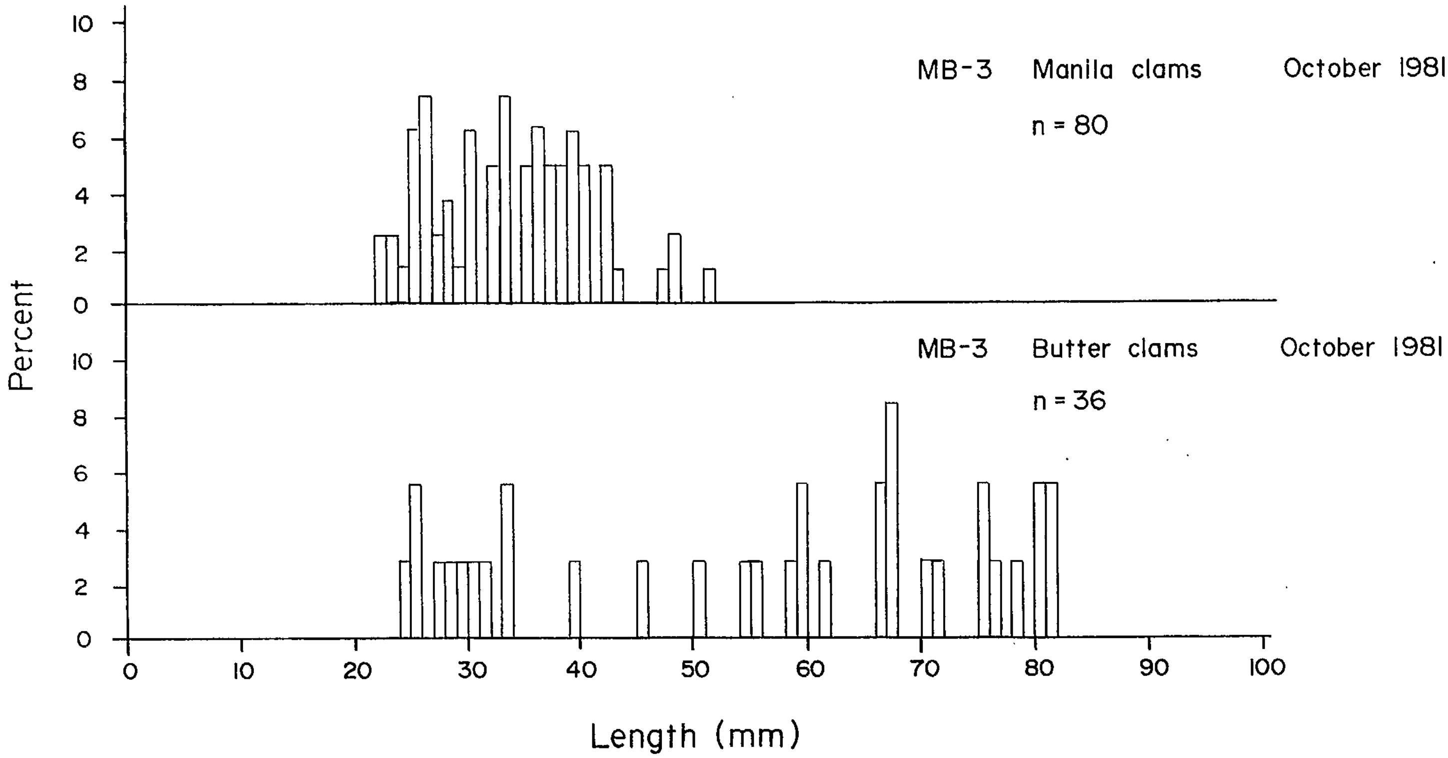


FIGURE 15. Length frequency histograms of littleneck, manila and butter clams from samples taken during October, 1981 at site MB-3.

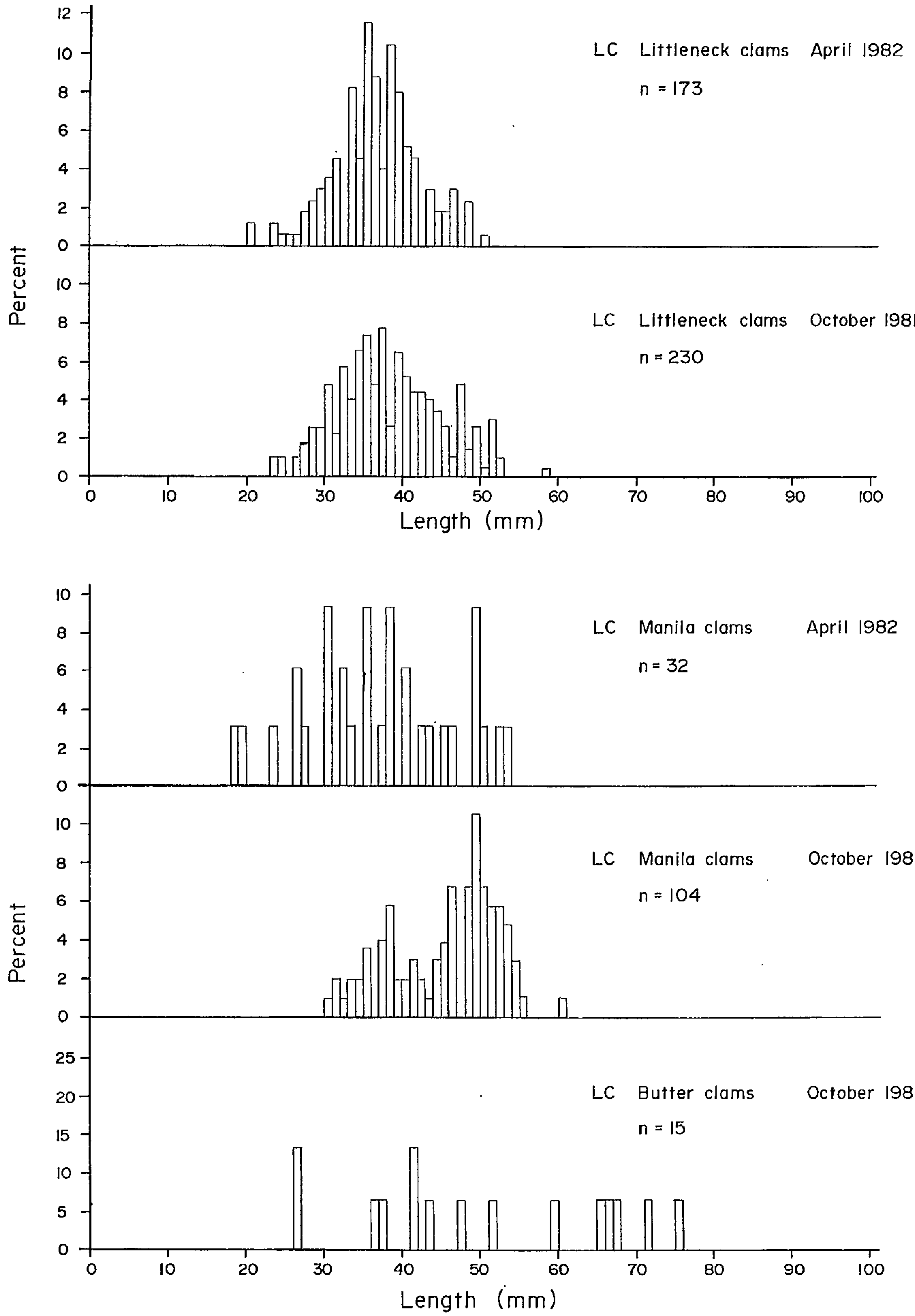


FIGURE 16. Length frequency histograms of littleneck, manila and butter clams from samples taken during October, 1981 and April, 1982 at site LC.

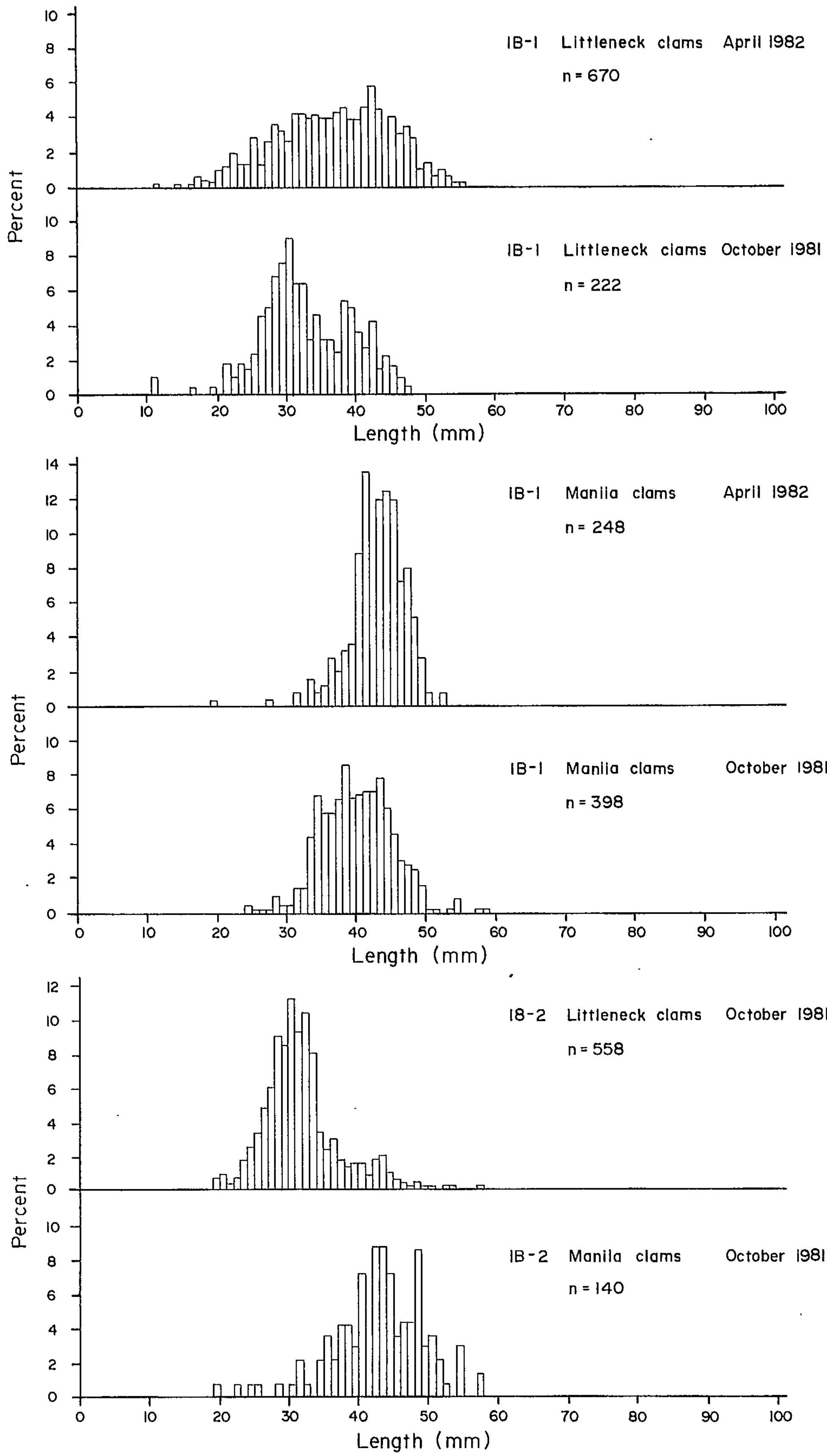


FIGURE 17. Length frequency histograms of littleneck and manila clams from samples taken during October, 1981 and April, 1982 from sites IB-1 and IB-2.

FIGURE 13. Associated harvest mortality.