Age and Size Structure in Five Populations of Geoduc Clams *(Panope generosa)* in British Columbia

P. A. Breen and T. L. Shields

Department of Fisheries and Oceans
Fisheries Research Branch
Pacific Biological Station
Nanaimo, British Columbia V9R 5K6

June 1983

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1169

Fisheries and Oceans Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1 - 456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457 - 714 were issued as Department of the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais que ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les scences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon regional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of

Fisheries and Aquatic Sciences No. 1169

June 1983

AGE AND SIZE STRUCTURE IN FIVE POPULATIONS OF GEODUC CLAMS (*Panope generosa*) IN BRITISH COLUMBIA

by

Paul A. Breen and Thomas L. Shields[1]

Department of Fisheries and Oceans

Fisheries Research Branch

Pacific Biological Station

Nanaimo, British Columbia V9R 5K6

[1] Archipelago Marine Research Ltd,

5 Helmcken Road,

Victoria, B.C. V8P 5M3.

Cat. No. Fs 97-6/1169 ISSN 0706-6457

ABSTRACT

Breen, P. A. and T. L. Shields. 1983. Age and size structure in five populations of geoduc clams (Panope generosa) in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 1169: iv + 62 p.

Geoduc clams (Panope generosa) were counted and sampled at five British Columbia sites. Samples were aged by counting growth rings on acetate peels made from shell sections. Mortality rates were estimated from age frequencies, and found to be in the range M = 0.01-0.02. These estimates and those of growth rate are similar to those seen in Washington State populations.

The effect of harvesting on sediment structure and meiofaunal community composition was also examined. Harvesting has no effect on sediment structure, and had only small effects on the meiofauna. Diversity apparently increased as a result of harvesting.

Density estimates showed that the fishery can reduce geoduc density to low levels. The distribution of geoducs within plots was uniform at both harvested and unharvested sites. We describe a method of counting geoducs that may result in more accurate estimates in future surveys.

Key words: Geoduc, geoduck, fishery, British Columbia, mortality, growth.

RESUME

Breen, P. A. and T. L. Shields. 1983. Age and size structure in five populations of geoduc clams (Panope generosa) in British Columbia. Can. Tech. Rep. Fish Aquat. Sci. 1169: iv + 62 p.

Le présent rapport porte sur l'échantillonnage et le dénombrement des geoducks (Panope generosa) à cinq emplacements de la Colombie-Britannique. La détermination de l'âge s'est faite à l'aide de copies sur acétate des parties d'oreillettes où les zones de croissance ont été comptées. Les taux de mortalité (M), évalués à partir des fréquences d'âge, variaient de 0,01 à 0,02. Ces estimations ainsi que celles des taux de croissance sont semblables à celles déterminées pour les popultions de l'Etat de Washington.

Nous avons aussi étudié l'incidence de l'exploitation sur la structure des sédiments et la composition de la méiofaune. L'exploitation n'influe pas sur la première et n'a qu'une faible répercussion sur la seconde. La diversité semble augmenter par suite de l'exploitation.

Selon les estimations de la densité des geoducks, la pêche peut la réduire à de faibles niveaux. La répartition des individus à l'intérieur de carrés était uniforme tant aux emplacements exploités que non exploités. Pour le dénombrement des geoducks, nous décrivons une méthode qui produira peut-être des estimations plus précises au cours des futurs levés.

INTRODUCTION

The geoduc (Panope generosa) is a large subtidal clam, widely distributed in the shallow waters of British Columbia. A commercial fishery for geoducs began in 1976, and landings quickly increased over the next several years (Harbo et al. in prep.). In 1981, geoducs comprised the highest landings among shellfish and had the third highest landed value, after shrimp and crabs. Landings in 1981 were 2704 metric tons (6 million pounds), worth $2,162,000.

Existing biological information about this species is scarce. The British Columbia government's Marine Resources Branch (MRB) carried out a survey of biomass on part of the southern BC coast (Cox & Charman 1980; Cox unpub. data), and from this work fishery managers estimated the total south coast stock size available to harvesters.

Rates of growth, recruitment and mortality are available from work carried out in Washington State (Anderson 1971; Goodwin 1976; Shaul & Goodwin 1982; pers. comm.) but in British Columbia these rates have so far been estimated only from two samples of geoducs collected by MRB in 1980 (Breen, unpub. data). From the latter work, it was estimated that natural mortality rates were low ($M<0.05$), recruitment rates were similarly low, and growth rates were roughly similar to those in Washington State. Yield modelling (Breen, unpub. data) carried out with those results formed the basis for annual quotas now imposed on the fishery (Harbo et al. in press).

Further information is clearly required by managers. Present estimates of sustainable yield are very sensitive to estimated natural mortality rates, so it is important to have more than two estimates. Also, the temporal pattern of recruitment is not well understood. Information from Washington State (Shaul & Goodwin 1982; pers. comm.) indicates a reasonably steady but very low supply of juveniles to the population. The effect of fishing on recruitment, to which yield estimates are again sensitive, is almost totally unknown.

The main objects of this study were, therefore, to obtain estimates of mortality, recruitment and growth rates from a larger number of B.C. populations. Geoducs can be aged (Shaul & Goodwin 1982), so these estimates could all be made by ageing representative samples from natural populations.

Several secondary objects were also carried out. First, we measured density and its associated variance in the populations sampled. This allowed us to examine the impact of harvesting on density that will allow more efficient design of future studies of abundance.

Second, we examined the 'show factor' in experimental plots, and examined the efficiency of initial counts. Again, this was done so that future surveys or measurements of density could be carried out in the most efficient way. The 'show factor' is the percentage of geoduc siphons that are actually visible to a diver at a given time. The siphons are visible if a geoduc is actively pumping water, but commonly some animals are inactive and have their siphons retracted below the sediment surface.

The 'show factor' varies seasonally from 5-60% (Goodwin 1977). If divers carrying out a survey count the visible siphons ('shows'), they can under-estimate the true number of individuals present. Using the method described below, it is possible to count some of those siphons which are partially retracted as well as the visible siphons. The study examined the efficiency of doing this.

Third, the study examined the effect of geoduc digging on the meiofauna and sediment composition. Both commercial and experimental digging of geoducs is done with jets of water directed into the sediment beside the geoduc's siphon. This activity appears to be highly disruptive of the substrate. After a geoduc has been removed, a shallow depression about 0.5 m in diameter remains for weeks or months. After digging, the sand within such depressions is in thick liquid suspension, and requires hours to settle out. A considerable quantity of sediment is also blown into large clouds, which quickly eliminate visibility in the immediate area. In addition to these purely physical effects, benthic fishes and cancerid crabs are attracted to the area, and can be found foraging in and near the holes several days after digging has taken place. We therefore examined one site for changes in sediment structure and meiofaunal community composition.

METHODS

Geoducs were counted and sampled at five sites on Vancouver Island. These sites were:

1) Brady's Beach, near Bamfield (Fig 1). This site had not been harvested. It was known from previous surveys (Cox, unpub. data) to support a high density of geoducs. During the summer of 1980 the Marine Resources Branch (MRB) removed geoducs for ageing from a well-marked site near here.

2) Sibell Bay, in Ladysmith Harbour (Fig 2). This site had also not been harvested.

3) Comox Bar, near Comox (Fig. 3). This site had been heavily harvested.

4) Elbow Bank, near Tofino (Fig 4.). This site had been heavily harvested.

5) James Island, near Sydney (Fig.5). This site had been heavily harvested.

The two unharvested sites were chosen from our knowledge of suitable virgin beds; the three harvested sites were chosen after discussing possible sites with representatives of the Field Services Branch, to whom logbook information is sent by fishermen.

Using SCUBA, each area was scouted to locate a suitable site. The criteria used in scouting were the presence and abundance of geoducs, evidence of commercial harvesting in the three harvested locations, and a maximum depth at high water of 12 m. The last criterion reduced the effect of no decompression time limits on working time.

At each site, 3-4 sample plots were constructed underwater as shown in Fig. 6. Each plot was 5 x 6 m, marked by steel re-inforcing rods driven into the substrate, and divided by reference lines into 6 rows each containing 5 quadrats, each quadrat 1 m square. Reference lines were 6 mm diameter rope marked into 1 m intervals. The plots at each site were separated by 2-3 m, and were arranged in a configuration determined by local topography and spatial characteristics of the bed.

On the day after plots were constructed, divers measured the abundance of geoducs by swimming along the reference lines and counting the numbers of 'shows' and other geoducs in each quadrat. Each diver held a 1 m long rod, against the reference line to indicate the width of the quadrat. The length of each quadrat was indicated by the marks on the reference lines. A 'show' was defined as a siphon visible and clearly identifiable to the diver. Other geoducs, with partially retracted siphons, were found by probing the shallow depressions their siphons left in the substrate. The siphon could be contacted with a finger, and always retracted further when touched in this way.

Geoduc density was estimated in two ways at all sites. Counts on the first day provided an initial estimate. A 'final' estimate was obtained from the total number of geoducs collected and counted in plots over the course of sampling (3-5 days). The relation between initial and final estimates is a 'correction factor' that could be applied to abundance measurements made by diver counts. At Brady's Beach only, the final estimate was obtained from the staked but unharvested plot.

The show factor (the percentage of geoduc siphons actually visible) was calculated for Brady's Beach and Sibell Bay. In the other 3 areas, fewer than 1% of the siphons were visible at any time, although they could be detected from the characteristic dimple left in the sediment surface.

A commercial-pattern dredge (Cox and Charman 1980) was used to collect geoducs. The divers collected 10-15 geoducs, then shut the dredge off, let the water clear, and searched the holes for juveniles. These often float to the surface of the liquefied sand. This is the method used by Lynn Goodwin of the Washington Department of Fisheries (pers. comm.) to collect a representative sample of geoducs from a population. The method is almost certainly size-selective, and may under-estimate the abundance of the first several year classes. However, the only alternative is to remove the entire sampled area with a suction dredge. Tests of such a method in Washington State (L. Goodwin, pers. comm.), and tests of a spot sampler in British Columbia (H. McElderry & B. Emmett, pers. comm.), show that this course is too time-consuming to be practical. Although the first few year-classes may be sampled less efficiently than older ones, the method used here should be equally efficient for all individuals above a threshold size. Tests made by Goodwin (pers. comm.) and the results below suggest that such a threshold is probably small.

The goal was to remove all geoducs from each harvested study plot to a maximum of 500 per site. That number was chosen to provide good estimates of age frequency based on previous work. Because digging both covers nearby siphons and creates a disturbance that causes geoducs to retract their siphons, wire stakes with flagging tape were used to mark locations of geoducs before digging was carried out. Plots were flagged daily until no unstaked siphons could be found.

A summary of the work at each site is given in Table 1. The goal of 500 individuals was reached at Brady's beach by digging one plot completely and one plot partially. The remaining plot was left untouched, except that staking was continued in order to arrive at a final estimate of density for comparison with the initial estimate. At the remaining four sites, the plots could not provide the 500 geoducs required, and digging also took place outside the plots. The same method of staking and digging was used outside the plots.

Geoducs collected were cut open, drained for at least an hour, and whole wet weight taken. Shell length was measured with calipers along the longest distance parallel to the hinge. Shells were removed, labelled, and saved for ageing. All the work described so far was carried out by Archipelago Marine Research Ltd. of Victoria.

Ageing was carried out as described by Shaul & Goodwin (1982). Briefly, the method consists of making a section through the hinge, polishing the section, and making an acetate peel of the section. Cutting and polishing was carried out under contract by John Colwell of Nanaimo. The peels were read under contract by Lee & Associates Ltd. of Nanaimo. For a number of reasons, not all sampled individuals could be aged from shell peels. Ages of small individuals (less than 100 mm shell length) were estimated from length frequency distributions and from the age-length relations derived from those individuals that were aged. The ages of individuals aged in this way were used only in constructing age frequencies, and not in constructing the age-length and age-weight relations shown below.

Mortality rates were estimated from regressions of log frequency vs age. Because the sampling method is probably less efficient for small (young) geoducs than for larger (older) ones, estimates of total mortality were made after eliminating the first ten age classes from the catch curve. Because the fishery has been operating for only six years, and since there is no reason to expect the fishery to have been greatly size-selective among the ages used to estimate mortality rate, the resulting estimates should reflect the natural mortality rate, M.

To look at changes in meiofauna, core samples were taken from three plots in the Brady's Beach study area in June 1982. These were:

Plot A) the control plot of the present study, from which geoducs had never been removed;

Plot B) the area from which the MRB had removed all geoducs during the summer of 1980;

Plot C) an area totally harvested in October 1981 by the present study.

Five cores were taken from each of these sites, using a plastic syringe tube 20 mm in diameter and 100 mm long. The uppermost 30 mm of sediment was preserved immediately in formalin to which Rose Bengal had been added. Later, the infauna were separated and identified to major taxa under contract by Dr. Charles Low of Nanaimo.

From each core sample, we calculated the Shannon-Weaver index of diversity (Pielou 1975):

$$H' = - p_i \log_{10} p_i$$

The mean number of organisms in each major taxa were also compared among plots with an analysis of variance.

To look at changes in sediment structure, cores were taken from the same plots at Brady's Beach just described, using a plastic cylinder 63 mm in diameter and 110 mm long. Three cores were removed from each site. The material was taken to the lab, separated into fractions with seives, washed with freshwater to remove salt, dried and weighed.

RESULTS

GEODUC DENSITY

Estimated densities at the five sites are shown in Table 2. Brady's Beach, a virgin site, had by far the highest density ($15/m^2$); the heavily harvested Comox Bar had the least ($0.16/m^2$). Among the remaining three sites, there was no clear pattern: density at the virgin Sibell Bay site was less than at the harvested Elbow Bank site.

At each site, variance around mean density was much less than the mean. This was true of both harvested and unharvested site. It means that, at least on the scale of distribution within 5 x 6 m plots, geoducs are not clumped or randomly distributed, but instead are evenly dispersed.

Show factors, as measured by continuous staking at Brady's Beach and Sibell Bay, were 22% and 57% respectively. The 'correction factor' ranged from 1.8-2.1 among the five sites. This ratio was nearly the same at Brady's Beach and Sibell Bay, even though the estimated show factors at these two sites were quite different.

POPULATION STRUCTURE

Age frequencies from the five sites are shown in Figs. 7 and 9-12. At each site, the majority of individuals were from 20-60 years old. No site yielded individuals in the range 1-10 years old in numbers that would be consistent with an ideal population (one with constant recruitment and mortality rates). Only at Elbow Bank were the numbers of 11-20 year old individuals close to those one would expect in such an ideal population.

At Brady's Beach, there appeared to be two strong modes in the age frequency - one centred near 25-30 years, and the other near 50 years (Figure 7). The MRB sampling in 1980, carried out within 30 m of the present sampling, yielded an age frequency with a very similar pattern (Figure 8).

There were also possible modes in the age frequency from Sibell Bay (Figure 9), near 25 and 45 years; and from James Island (Figure 12), near 25 and 40 years. Modes in the age frequencies from Comox Bar and Elbow Bank are much less clear.

RECRUITMENT

The paucity of young geoducs yielded by sampling has already been seen in the age frequencies just discussed (Figs 7-12). The exact numbers of juveniles aged 1-5 and 6-10 years are given in Table 3. The unharvested sites tended to have more juveniles than the harvested sites, except that the harvested Elbow Bank had the greatest number of 6-10 year olds. However, individuals from 1-10 years old comprised only 5% of the total sample overall.

NATURAL MORTALITY RATE

Mortality rates estimated from age frequency distributions are shown in Table 4. In the Comox data, the form of the age frequency curve led to a very low mortality estimate. In the remaining sites estimated mortality rate ranged from 0.0139 to 0.0190.

GROWTH

Relations between age and length, and age and whole wet weight, are shown in Figs. 13-17 and 21-22 respectively. The mean lengths and weights of aged individuals are given in Table 5.

Growth in length appears to be very rapid during the first 10 years, and then slows dramatically. At age 10, most individuals have reached a length close to their final length. If there is any growth after age 20, it is masked by variability in these data.

The relation between age and weight is more variable (Figs. 18-22). There appears to be a rapid increase in weight during the first ten years of life, then a period of slower growth which may continue for many years. At James Island (Fig. 22), weight appeared to increase over the first 50 years of life.

Mean weights were quite different among the five sites (Table 5), and these differences could not be accounted for by differences in mean age. Elbow Bank and Sibell Bay geoducs were the largest, and were nearly twice the average weight of geoducs at Brady's Beach. Mean lengths followed the same pattern.

MEIOFAUNAL COMMUNITY STRUCTURE

The mean numbers of individuals in major taxa found in sediment core samples are shown in Table 6. Variances among samples from the same plot were very high; consequently only one significant difference was seen among the mean numbers of individuals among sites. The trends shown by the means are also given in Table 6. If geoduc digging has any effect on meiofauna, the effect is not a simple one: some species increased in abundance after experimental digging and others decreased. Generally, meiofauna decreased as a result of disturbance, but some harpacticoids increased.

The plots completely harvested in October 1981 and in the summer of 1980 had visibly less algal cover. In particular, the small red alga Pterosiphonia dendroidea formed 5-10% bottom cover in undisturbed areas but was absent from harvested plots.

Diversity from each sample is shown in Table 7. The undisturbed plot showed the lowest diversity, and the most recently disturbed showed the highest diversity.

SEDIMENT STRUCTURE

Sediment analysis of samples from the three plots at Brady's Beach is summarized in Table 8. There was clearly no difference among the three plots. The size fractions of particles 125-500 microns in diameter comprised most of the sediment.

INCIDENTAL OBSERVATIONS

In every area except Comox Bar, the sampling operation attracted an assortment of bothid and pleuronectid fishes, and the crabs Cancer magister, C. gracilis and C. productus. The fishes were especially closely attracted to digging, and would often swim within a few centimeters of the diver's hand to take organisms blown out of the substrate. Crabs were frequently observed feeding on geoducs of all sizes that had floated to the top of digging holes. A flatfish was observed feeding on a small geoduc only once, but more may have been lost in this way. Because of the sediment clouds created by digging, it was not possible to inspect the holes until several minutes had been allowed for the water to clear.

DISCUSSION

The results shown above confirm existing ideas about growth, mortality, and recruitment patterns in geoducs.

The ages of geoducs taken by our sampling ranged to 124, and the mean age in all samples was near 40. The populations we observed contained few juveniles, but at the same time showed no evidence of sporadic year-class strength. Instead, the age frequencies support the contention of Shaul & Goodwin (pers. comm.) that recruitment in geoducs is constant and low. Although the sampling method may be biased against the first several year-classes, we saw no evidence that harvesting has stimulated recruitment.

Shaul & Goodwin (pers. comm.) estimated mortality rates from age frequencies in several Washington State populations. They obtained estimates that ranged from 0.02-0.05. The estimates obtained in this study range from 0.01-0.02 in four populations. As explained above, the fishery has operated only for a short time and one can assume that it takes adult geoducs without appreciably changing the underlying population age structure. Thus, even at the three harvested sites sampled, the estimate of mortality rate reflects natural mortality.

The assumptions underlying mortality estimates are that recruitment has been roughly constant during the time that the aged geoducs were recruited, and that mortality rate is similar for all ages. The second assumption probably holds well, except perhaps for the first ten year-classes; these were omitted from the data used to make these estimates. The first assumption may not hold. Three of the age frequencies show modes around 25 and 50 years of age; the results of 1980 sampling at Brady's Beach showed similar modes. Also, the frequency of individuals up to 20 years old is lower than one would predict from the frequency of older individuals. These data might suggest that settlement of juvenile geoducs has periodic peaks with a low amplitude and a long period. Failure of assumptions of the method might cause errors in mortality rate estimates. There is no way at present to evaluate this problem.

Growth also was similar to that reported by Goodwin (1976). Geoducs appear to have very rapid growth until age 10 or so, then growth in length virtually stops, and growth in weight shifts to a slower rate that persists for many years.

Whatever the long-term pattern of recruitment, it is clear that present populations of geoducs have very low turnover rates. The results of this study therefore suggest that sustainable yields of geoducs might be a small fraction of virgin stocks.

In the five populations studied, adult size of geoducs differed considerably. More than five sites would be needed to examine the factors affecting adult size, but the five sites in the present study can be graded according to their exposure to surge. Brady's Beach is the most exposed site, receiving oceanic swells. Elbow Bank and Sibell Bay are both sheltered places. Comox Bar is exposed to Georgia Strait during SE weather, and James Island is exposed to Haro Strait. The sizes of adult geoducs follow the same pattern: geoducs were smallest at Brady's Beach and largest at Elbow Bank and Sibell Bay.

The results of density measurements have implications for any future surveys that may be conducted. First, the ratio of mean to variance showed that geoducs were evenly distributed within plots in both harvested and unharvested sites. Considering the size and number of adults in a dense population (such as that at Brady's Beach), this is not surprising. It is less clear how an even distribution remains after harvesting. Cox & Charman (1980) and Cox (unpub.) found that the variance around mean density measured in widely spaced transects was much greater than the mean (about 100:1). Because the variance is so much greater between transects than within transects, the problem of determining point density is much easier than estimating total abundance. Efficient survey design should address this, perhaps by increasing the number of transects and decreasing the number of quadrats per transect.

Our results also suggest that density would best be estimated by having divers count both the visible siphons and the partially retracted siphons, as long as they could be sure of the species identity of partially retracted siphons. The ratio of our initial counts to the 'final' estimate of density was quite constant, even though the study extended from early fall into winter, and even though the show factors were very different at two of the sites. Since show factors vary with season (Goodwin 1977), and perhaps also with hydrographic conditions and sea state, our suggested 'correction factor' might be more accurate in estimating the true density.

The effect of geoduc harvesting on geoduc populations obviously needs more study. We saw no measurable effect on recruitment, and it was too early to be able to see any growth effects. The obvious effect of harvesting is to reduce geoduc density. Previous density at the harvested sites was not known, but the fishery was apparently able to reduce density to $0.6/m^2$ at James Island and to $0.2/m^2$ at Comox Bar. Cox (unpub.) regarded densities less than $0.3/m^2$ to be 'negligible'. Thus, it may be true that the fishery leaves an area when the density becomes too low to be economical; but that density is a small fraction of initial density.

We found no evidence of changed sediment structure caused by experimental harvesting at Brady's Beach. The experimental work was, if anything, more destructive than commercial fishing - the experimental work attempted to obtain every geoduc, and experimental divers are less efficient and more disruptive of the substrate than commercial geoduc harvesters. Goodwin (1978) reported similar findings from a similar study. With respect to meiofaunal communities, we found a significant difference in abundance in only one taxon among the three sample plots. The variances involved suggest that significant results might be obtained with much larger sample sizes, but this would be costly. Diversity appears to increase as a result of harvesting, implying that meiofaunal communities are strongly structured by competition.

ACKNOWLEDGMENTS

We were assisted in field work by Howard McElderry, Brian Emmett, and Peter Bentley. We also thank Bob Baden and Anne Stewart, who provided us with accomodation and help during the field work; Wolfgang and Darlene Carolfeld and Lana Fitzpatrick for their help in diving; Lorne Collicut, Peggy Frank, and Sue McCormack for processing samples; Tom Brown and Bev Kask for their advice on core sampling; Lorne Collicut, John Brouwer and Jim Lane for making acetate peels; Rose Curtis for her patience in reading them; Wolfgang Carolsfeld, Lorne Collicut, and Kerry Hobbs for their computer time. Dr. Neil Bourne provided invaluable assistance during ageing, and with Jim Boutillier provided helpful criticism of the manscript.

LITERATURE CITED

Anderson, A. M. 1971. Spawning, growth, and spatial distribution of the geoduck clam, Panope generosa Gould in Hood Canal, Washington. PhD. thesis, University of Washington, Seattle. 133 pp.

Cox, R. K., & E. M. Charman. 1980. A survey of abundance and distribution (1977) of the geoduck clam Panope generosa in Queen Charlotte, Johnstone and Georgia Straits, British Columbia. Marine Resources Branch Fisheries Development Report 16:122 pp.

Goodwin, L. 1976. Observations on spawning and growth of subtidal geoducks (Panope generosa, Gould). Proc. Nat. Shellfish. Assoc. 65:49-58.

Goodwin, L. 1977. The effects of season on visual and photographic assessment of subtidal geoduck clam (Panope generosa Gould) populations. Veliger 20(2):155-158.

Goodwin, L. 1978. Some effects of subtidal geoduck (*Panope generosa*) harvest on a small experimental plot in Puget Sound, Washington. Progress Report No. 66, State of Washington Dept. Fisheries. 21 pp.

Harbo, R., B. E. Adkins, P. A. Breen, and K. Hobbs. In prep. Age and size in market sampled geoducs (*Panope generosa*). Can. Tech. Rep. Fish. Aquat. Sci.

Pielou, E. C. 1975. Ecological diversity. Wiley & Sons, New York, 165 pp.

Shaul, W., & L. Goodwin. 1982. Geoduck (*Panope generosa*: Bivalvia) age as determined by internal growth lines in the shell. Can. J. Fish. Aq. Sci. 39:632-636.

Table 1. Summary of sampling effort at the five sites.

Site	Dates sampled 1981	# plots (5x6 m)	Areas sampled (m^2)			# geoducs collected
			plots	outside	total	
Brady's Beach	7-12 Oct	3	60	-	60	504
Sibell Bay	14-19 Nov	4	90	790	880	507
Comox Bar	14-19 Oct	4	120	2050	2170	221
Elbow Bank	7-12 Nov	4	120	950	1070	486
James Island	1-4 Nov	4	120	1520	1640	264

Table 2. Estimates of geoduc density at each site, and estimates of show factor from two sites. See text for details of methods used.

Site	Density (#/m^2)				show factor
	initial estimate	s^2	final estimate	ratio of final/initial	
Brady's Beach	8.20	3.64	14.73	1.80	22%
Sibell Bay	0.75	0.11	1.36	1.81	57%
Comox Bar	0.09	0.01	0.16	1.78	-
Elbow Bank	0.74	0.09	1.46	1.97	-
James Island	0.28	0.04	0.59	2.11	-

Table 3. Juvenile geoducs discovered by sampling at the five sites.

Site	Total number sampled	Ages 1-5	Ages 6-10
Brady's Beach	504	17	4
Sibell Bay	507	10	11
Comox Bar	221	0	0
Elbow Bank	486	5	29
James Island	246	3	4
Total	1982	35	48

Table 4. Estimated total mortality rate at each of the five sites. Mortality rate was estimated from the slope of regressions of natural log of frequency on age.

Site	estimated mortality rate
Brady's Beach	0.0190
Sibell Bay	0.0139
Comox Bar	0.0006
Elbow Bank	0.0177
James Island	0.0185

Table 5. Mean length and weight of aged geoducs at the five sites.

Site	Mean age (yrs)	Mean length (mm)	Mean weight (g)
Brady's Beach	42.8	134.0	699.2
Sibell Bay	38.2	158.9	1277.2
Comox Bar	46.2	153.3	915.1
Elbow Bank	34.8	163.9	1192.1
James Island	40.5	149.1	915.1

Table 6. Mean numbers of organisms in major taxa found in sediment cores taken in three plots at Brady's Beach in June 1982. Plot A was undisturbed, Plot B had been totally harvested in July 1980, and Plot C had been totally harvested in October 1981. The gradient from Plot A to B to C is therefore one of increasing disturbance. The 'trend' indicates whether mean numbers of organisms increased or decreased over this gradient. Significance of the differences among plots was determined with a two-way analysis of variance.

Taxon	Treatment means			significance	trend
	plot A	plot B	plot C		
Foraminifera					
Cibicides lobulata	468.80	389.80	274.20	NS	decreasing
Cibicides refulgens	24.20	17.20	11.40	NS	decreasing
Elphidiella sp.	190.00	166.60	122.20	NS	decreasing
Eponides sp.	406.80	318.00	275.40	NS	decreasing
Quinqueloculina sp.	74.40	69.60	66.40	NS	decreasing
Nonionella sp.	37.40	47.60	24.60	NS	
Urnula sp.	23.60	41.80	20.20	NS	
Robulus sp.	91.60	99.40	129.80	NS	increasing
other foraminifera	21.40	17.80	13.20	NS	decreasing
Harpacticoida					
Ectinosamatidae	29.20	30.00	56.60	NS	increasing
other harpacticoids	25.00	66.20	102.60	.05	increasing
harpacticoid nauplii	50.40	66.80	61.80	NS	
all molluscs	7.00	4.20	3.00	NS	decreasing
all ostracods	34.20	21.60	18.20	NS	decreasing
all polychaetes	2.20	1.60	2.20	NS	
all amphipods	2.20	2.00	4.40	NS	
all nematods	409.00	453.20	253.20	NS	

Table 7. Shannon-Weaver diversity indices calculated for each core sample of meiofauna taken as described in table 6.

Plot	sample	diversity	mean
A	1.	0.8426	
	2.	0.8989	
	3.	0.8679	
	4.	0.8657	
	5.	0.8578	
			0.8666
B	1.	0.9168	
	2.	0.9584	
	3.	0.9166	
	5.	0.8758	
	6.	0.9322	
			0.9200
C	1.	0.9926	
	2.	0.9794	
	3.	0.8984	
	4.	0.9822	
	5.	0.9756	
			0.9656

Table 8. Sediment structure in core samples taken from 3 plots at Brady's Beach in May 1982. Plot A was undisturbed, plot B had been totally harvested in July 1980, and plot C had been totally harvested in October 1981. Upper table shows dry weights (g); lower table shows percentages.

	Fraction size							
	mm			m				
	>2.0	1.2-2.0	0.5-1.0	250-500	125-250	63-125	<63	Total
Plot A	4.13	4.64	3.98	750.7	561.9	62.9	10.26	1398.5
Plot B	5.08	3.87	4.08	926.9	556.4	69.4	8.10	1573.8
Plot C	4.21	3.52	4.10	289.0	1051.0	110.5	9.43	1471.8
Plot A	0.3	0.3	0.3	53.7	40.2	4.5	0.7	100.0
Plot B	0.3	0.2	0.3	58.9	35.4	4.4	0.5	100.0
Plot C	0.3	0.2	0.3	19.6	71.4	7.5	0.6	99.9

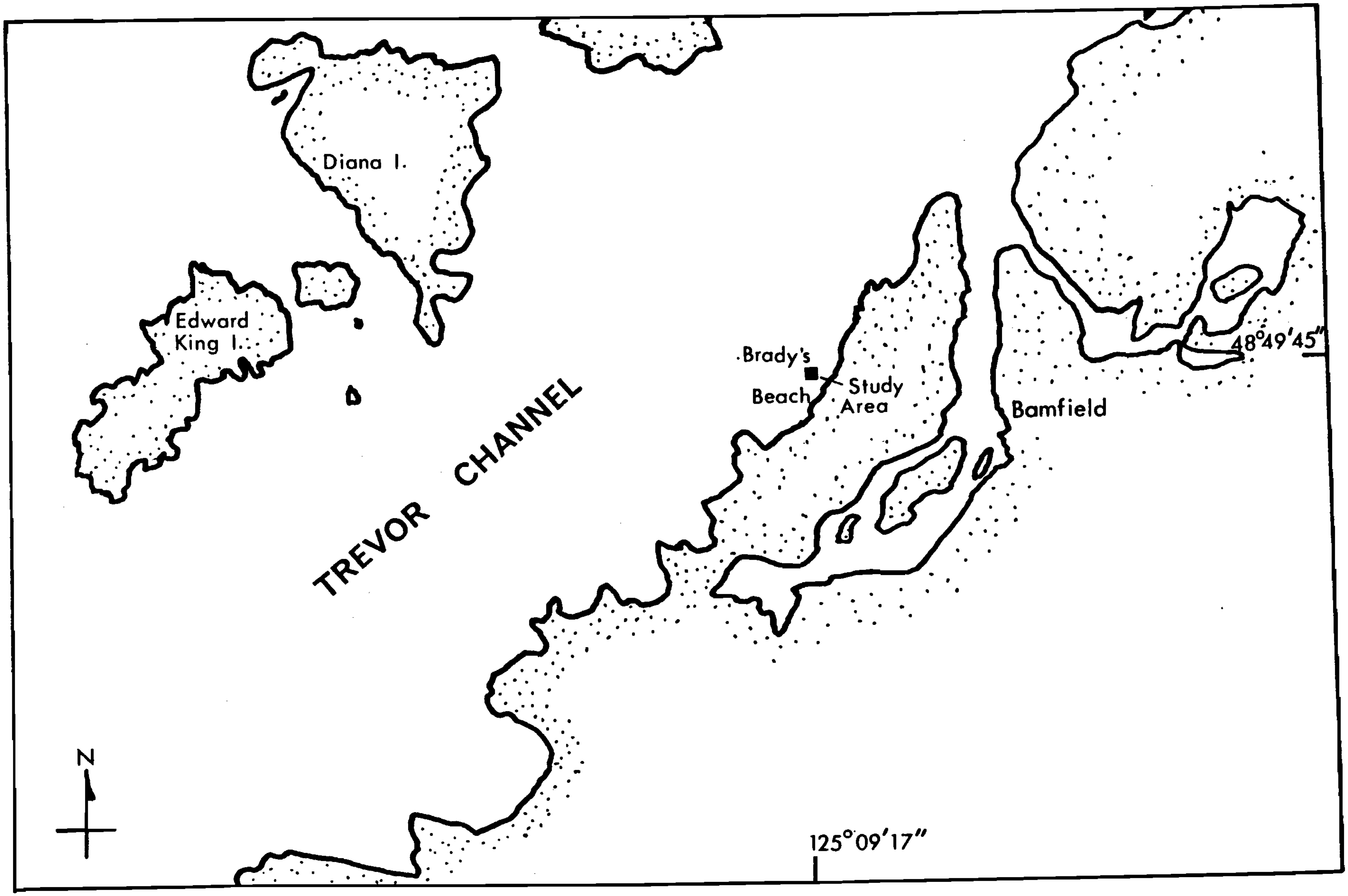

Fig. 1. Study site location at Brady's Beach.

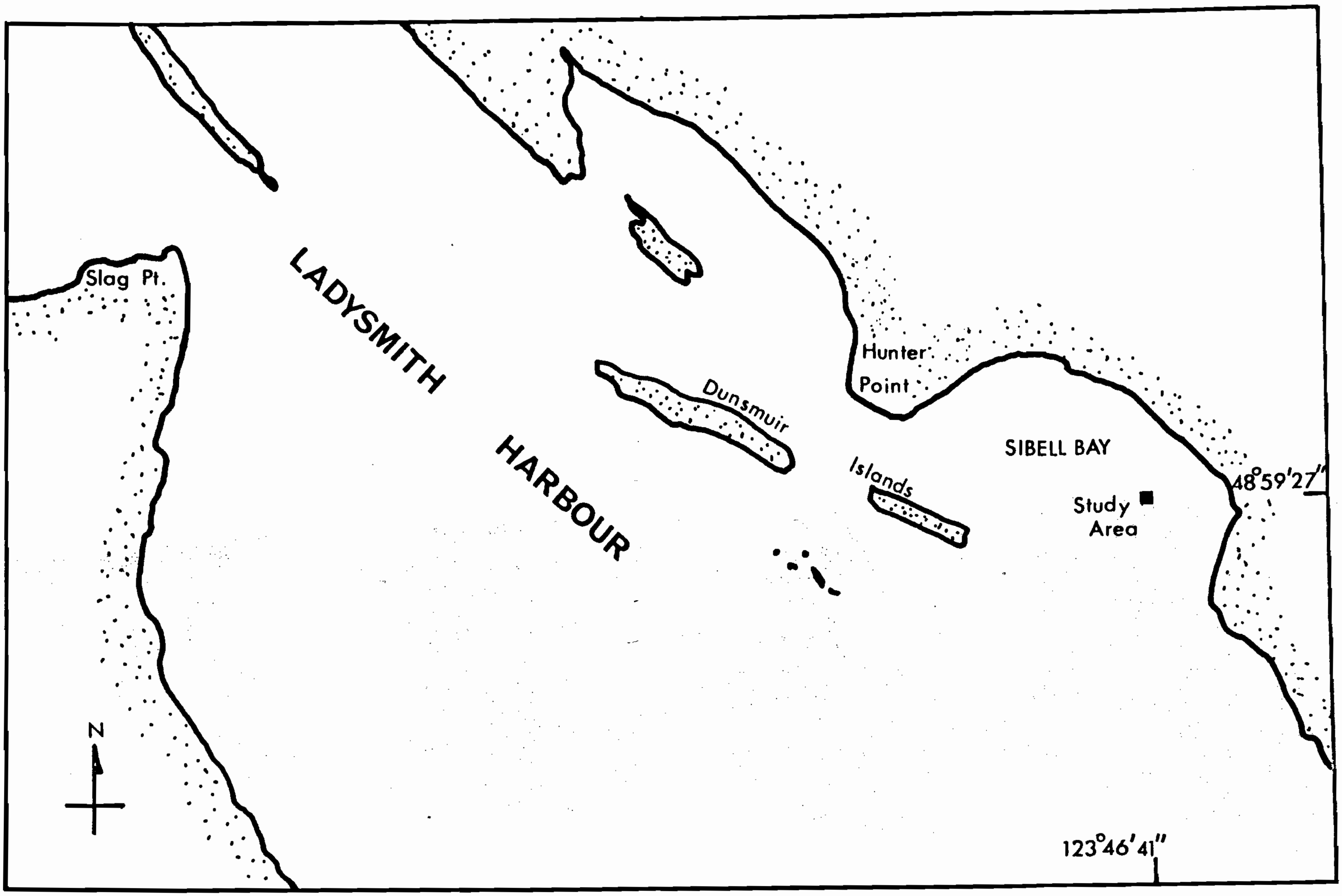

Fig. 2. Study site location at Sibell Bay.

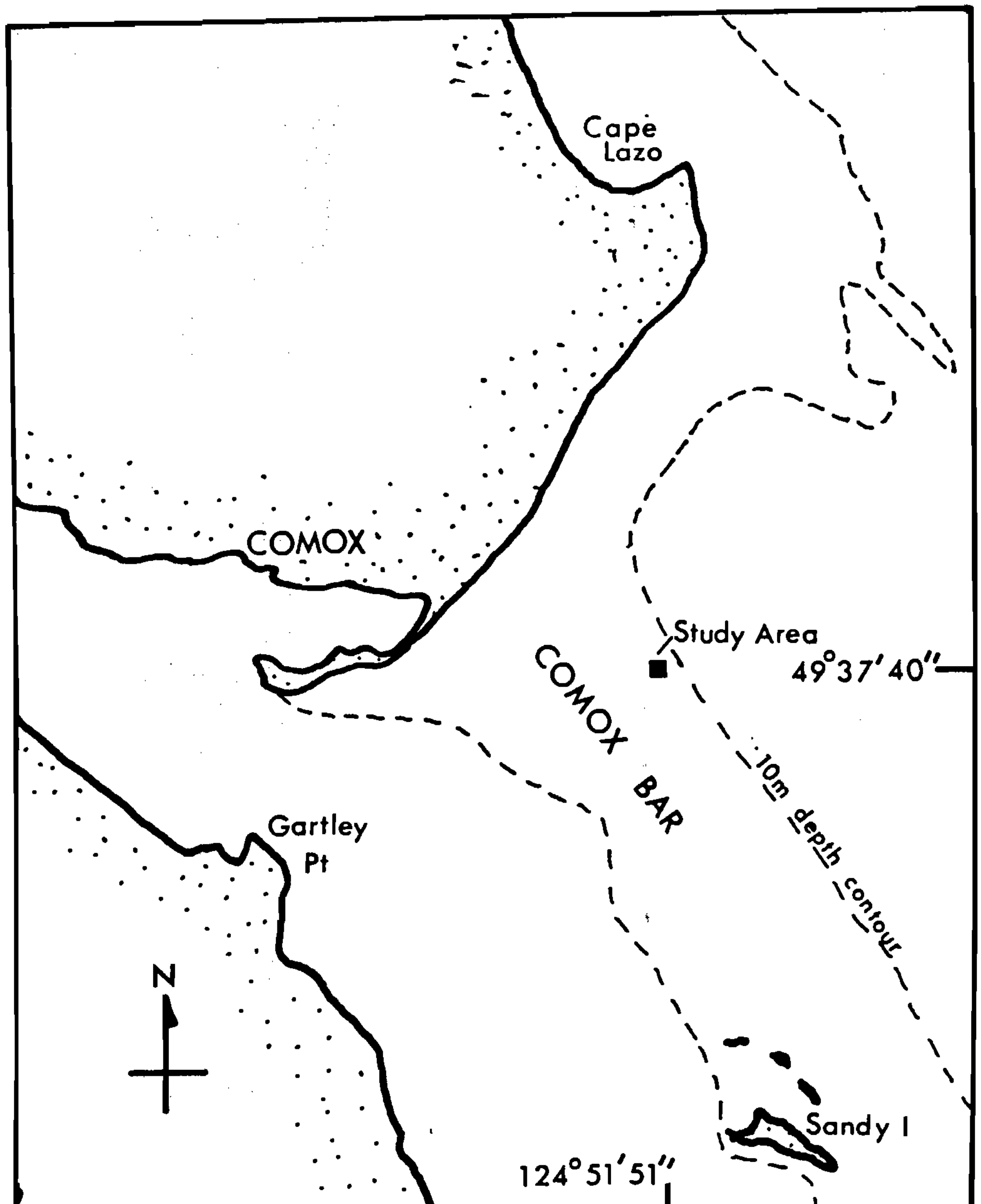

Fig. 3. Study site location at Comox Bar.

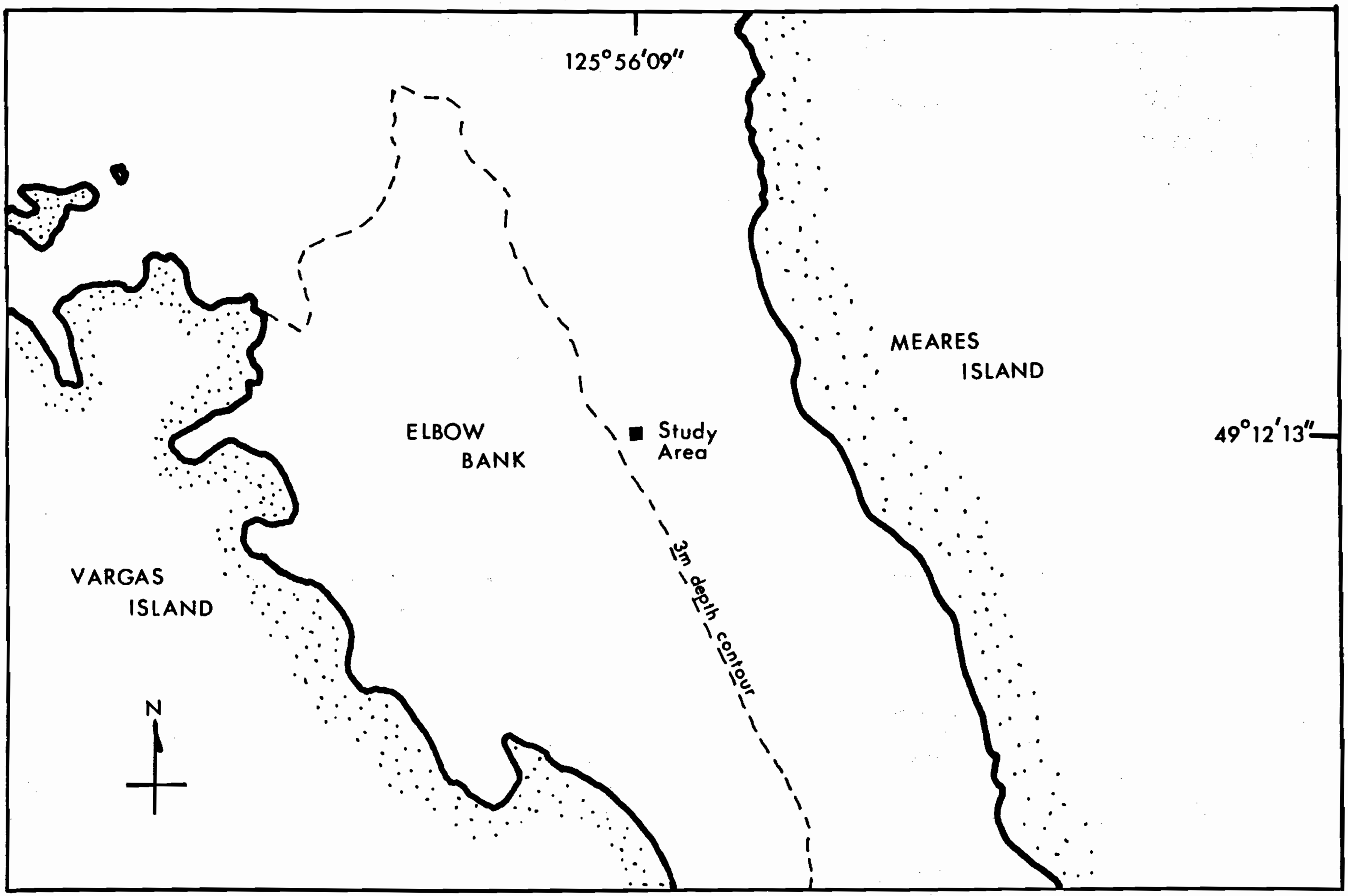

Fig. 4. Study site location at Elbow Bank.

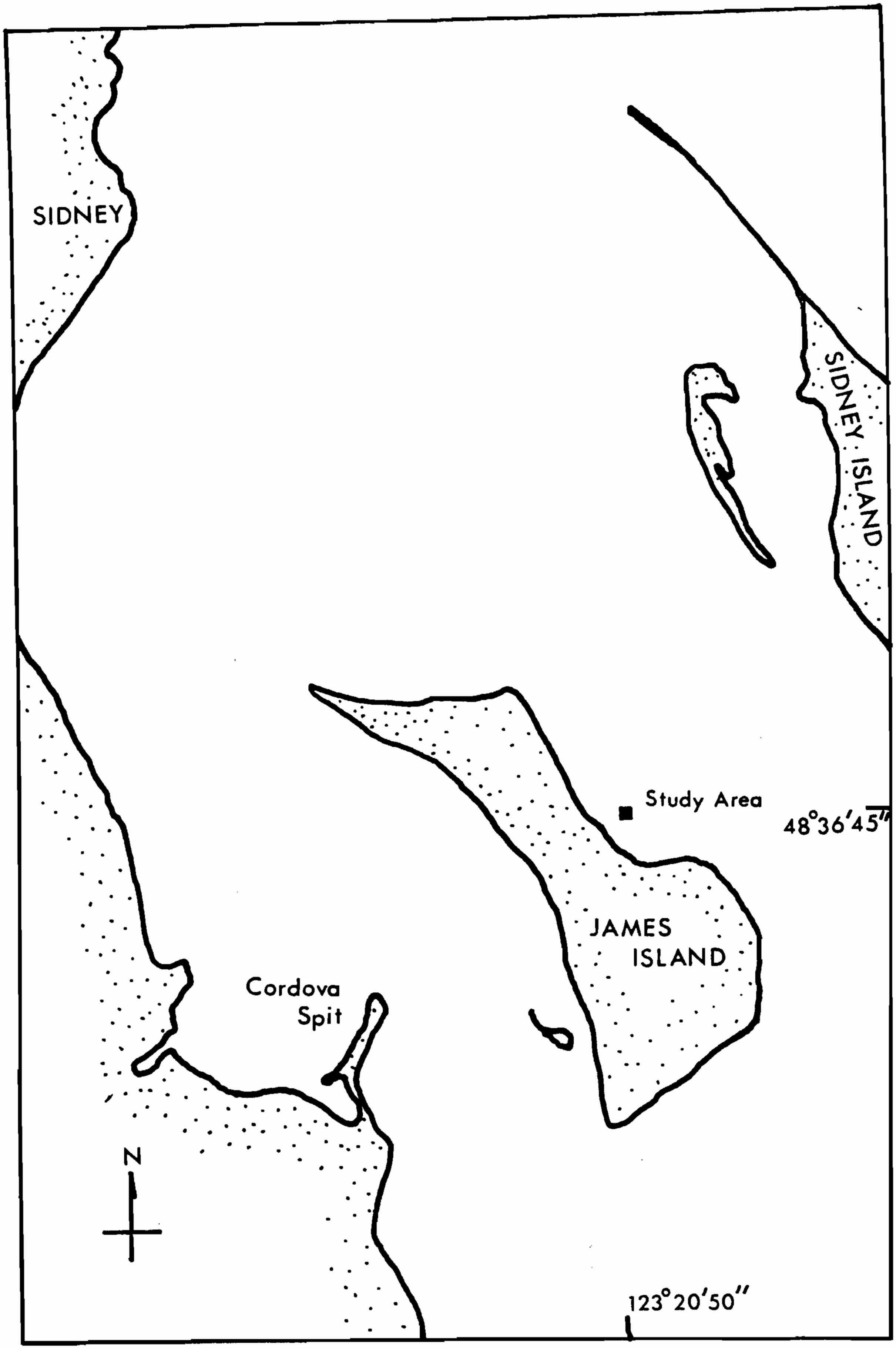

Fig. 5. Study site location at James Island.

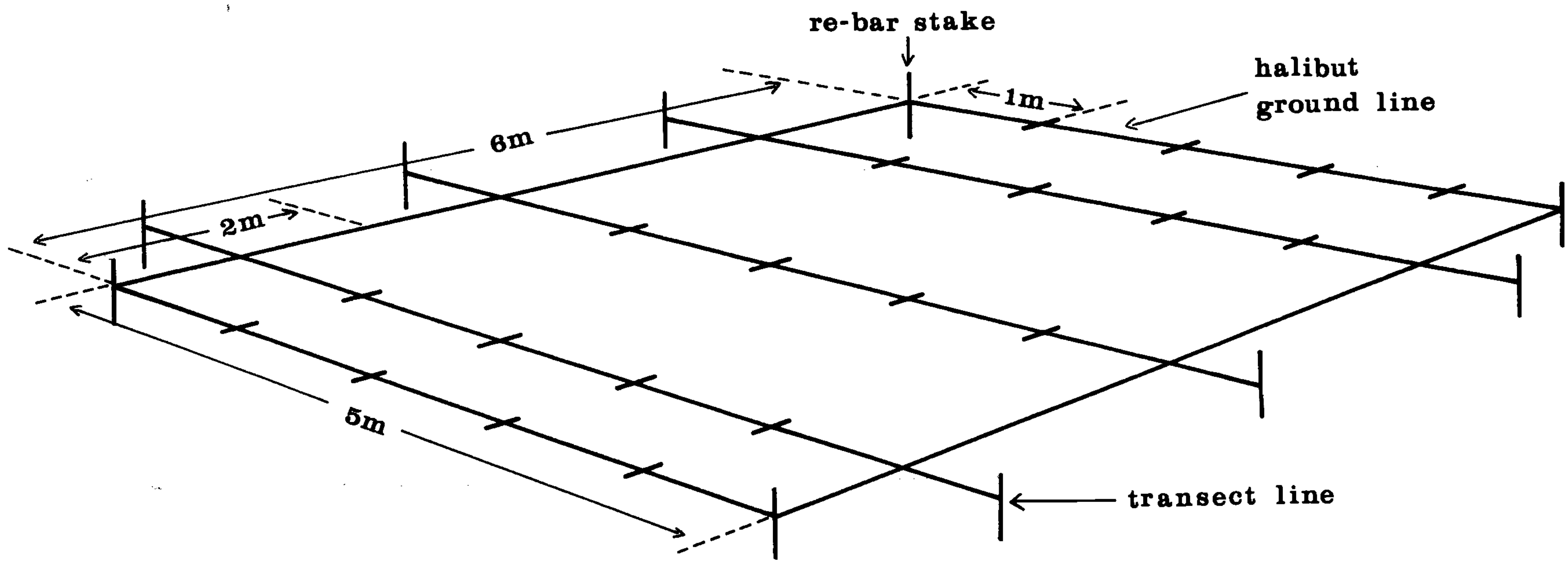

Fig. 6. Quadrat sample plot and transect lines for sampling geoduc population densities.

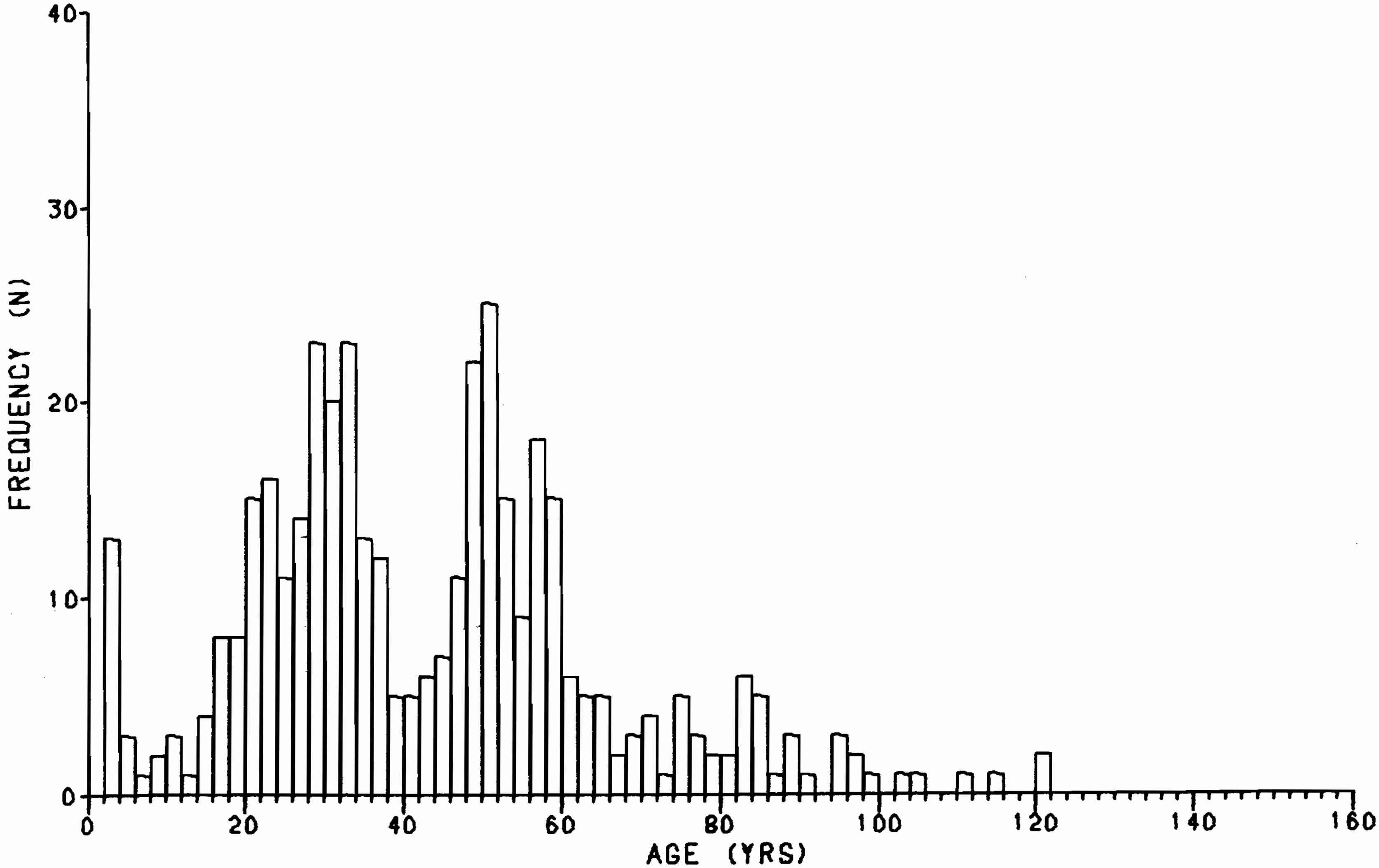

Fig. 7. Plot of age frequency, Brady's Beach, September 9, 1981.

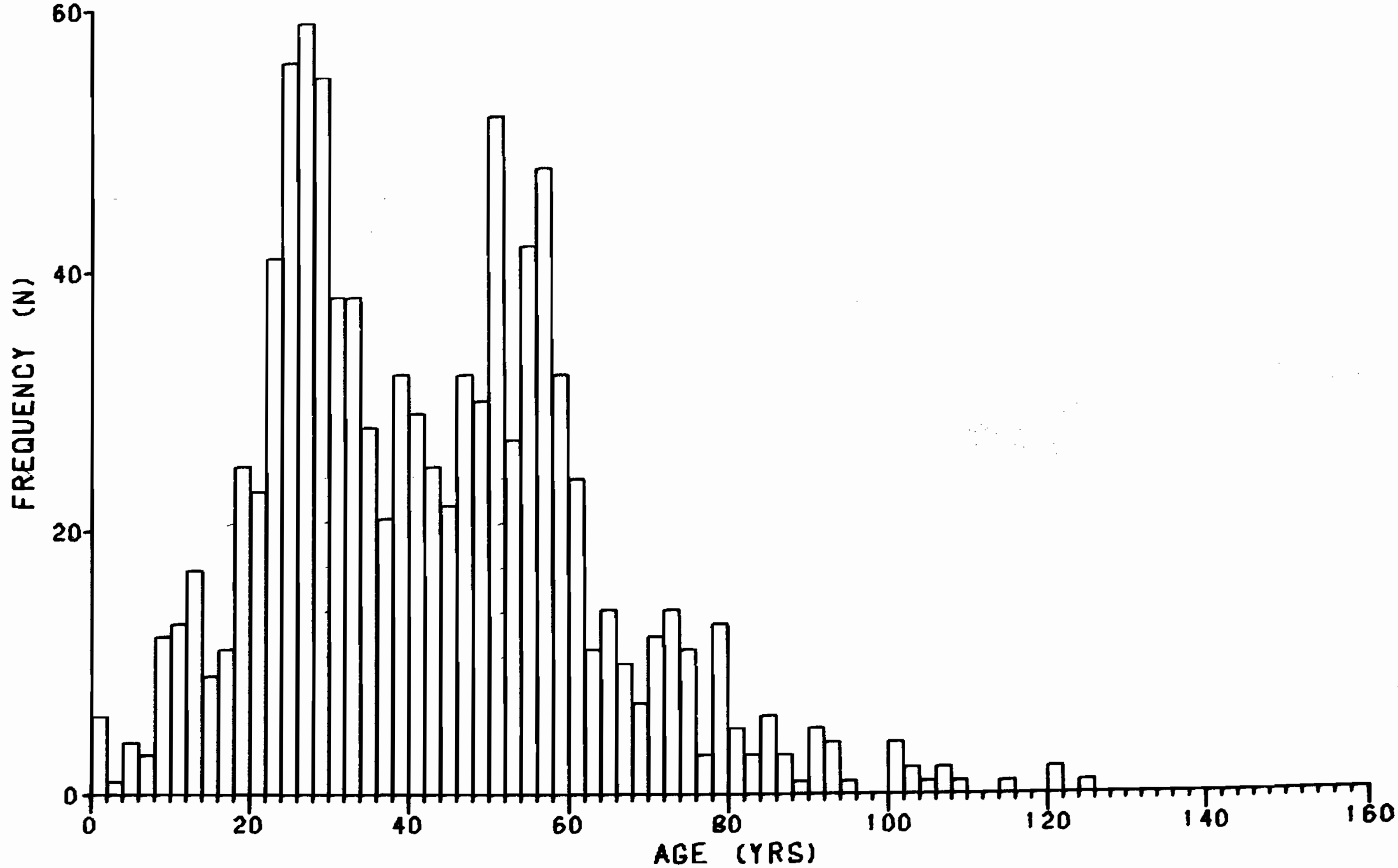

Fig. 8. Plot of age frequency, Brady's Beach, June 1980.

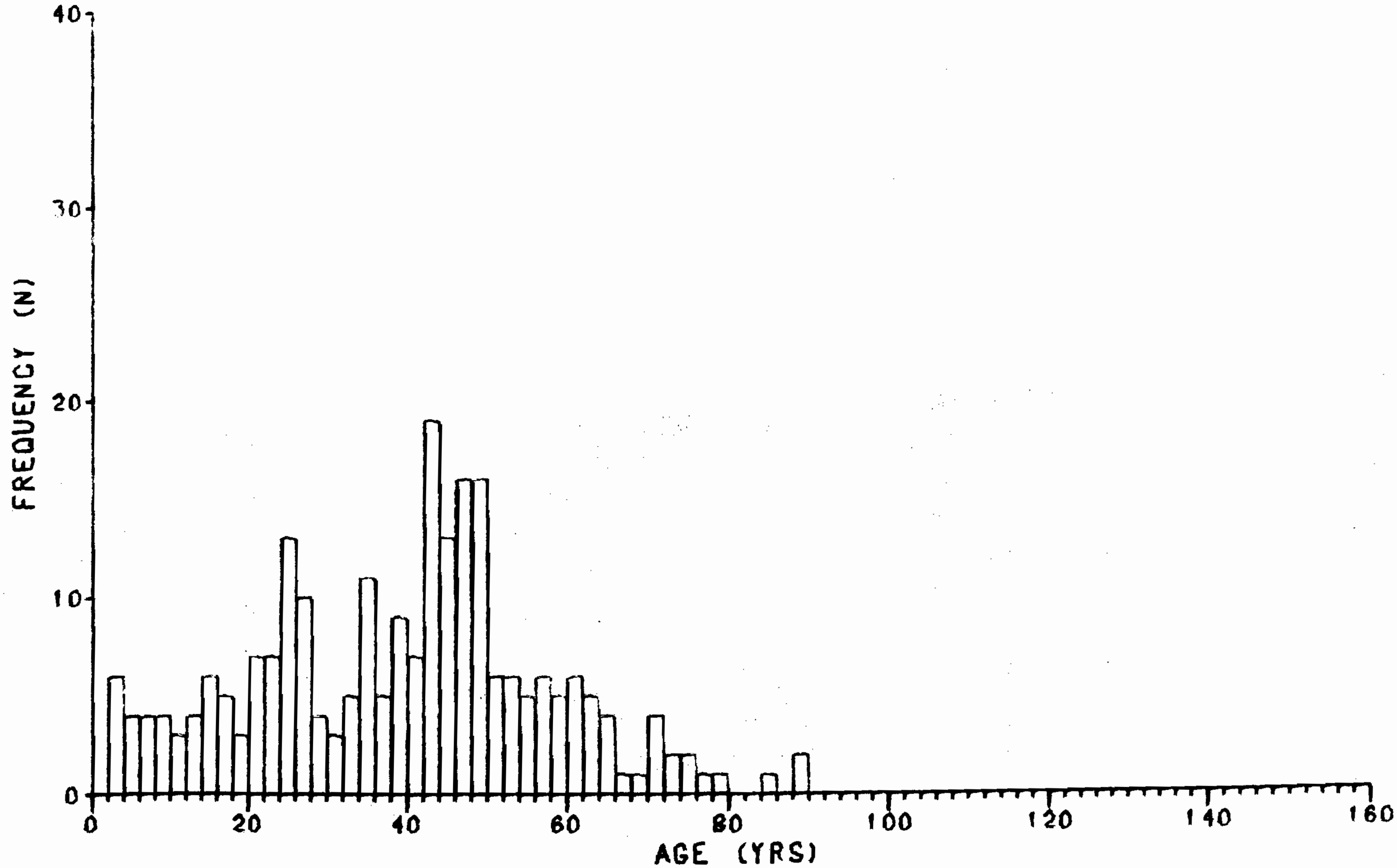

Fig. 9. Plot of age frequency, Sibell Bay, November 15, 1981.

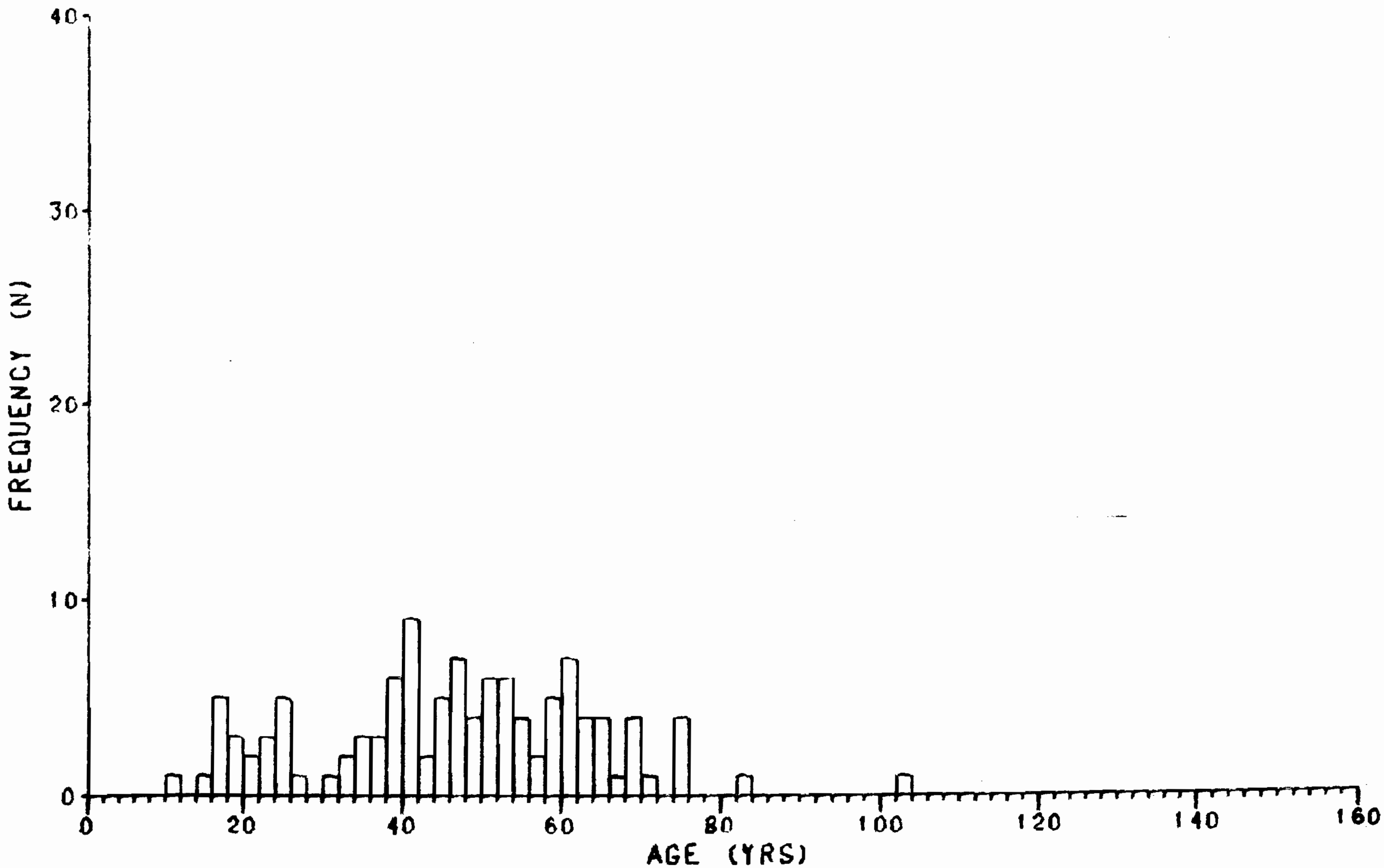

Fig. 10. Plot of age frequency, Comex Bar, October 16, 1981.

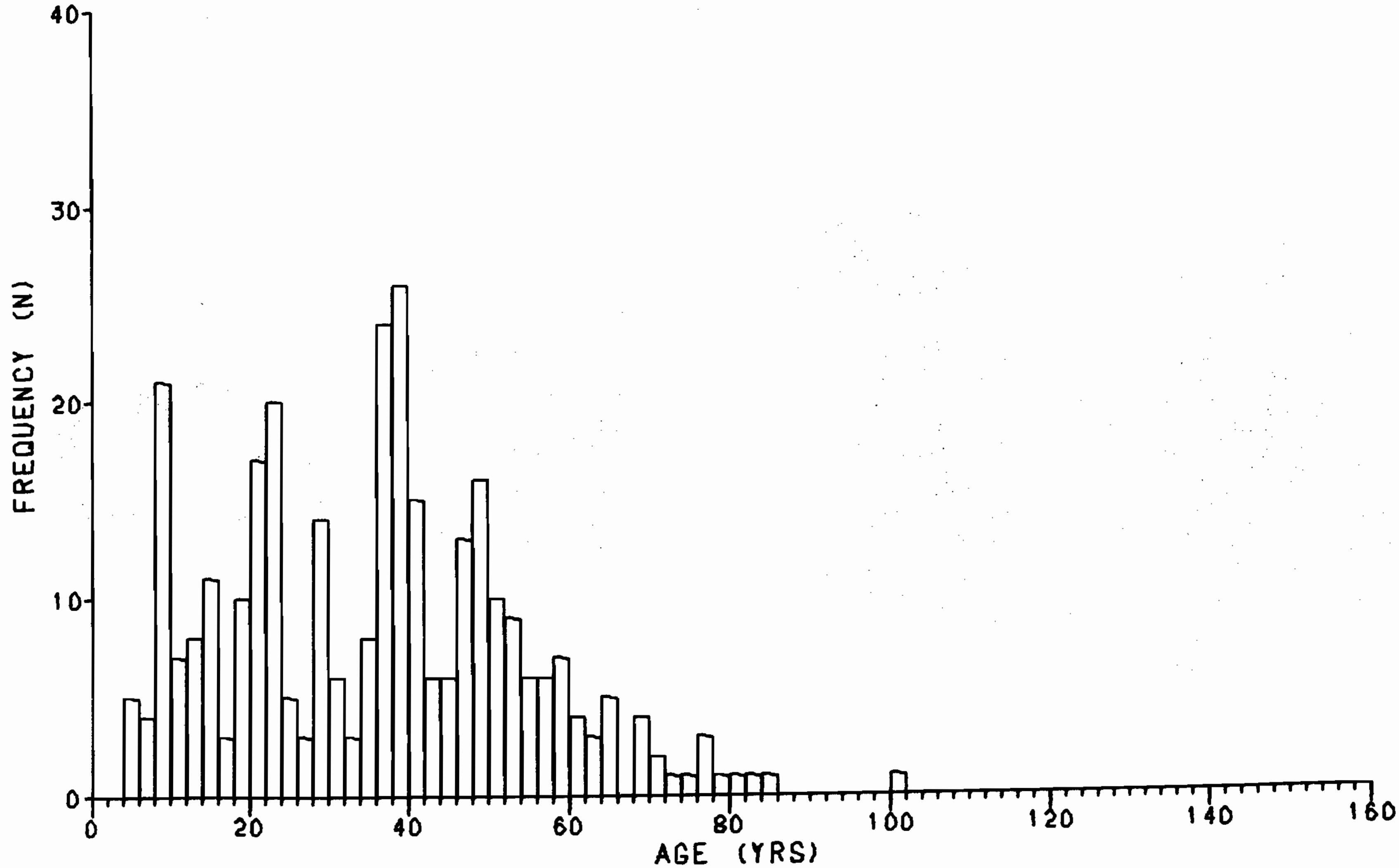

Fig. 11. Plot of age frequency, Elbow Bank, November 7, 1981.

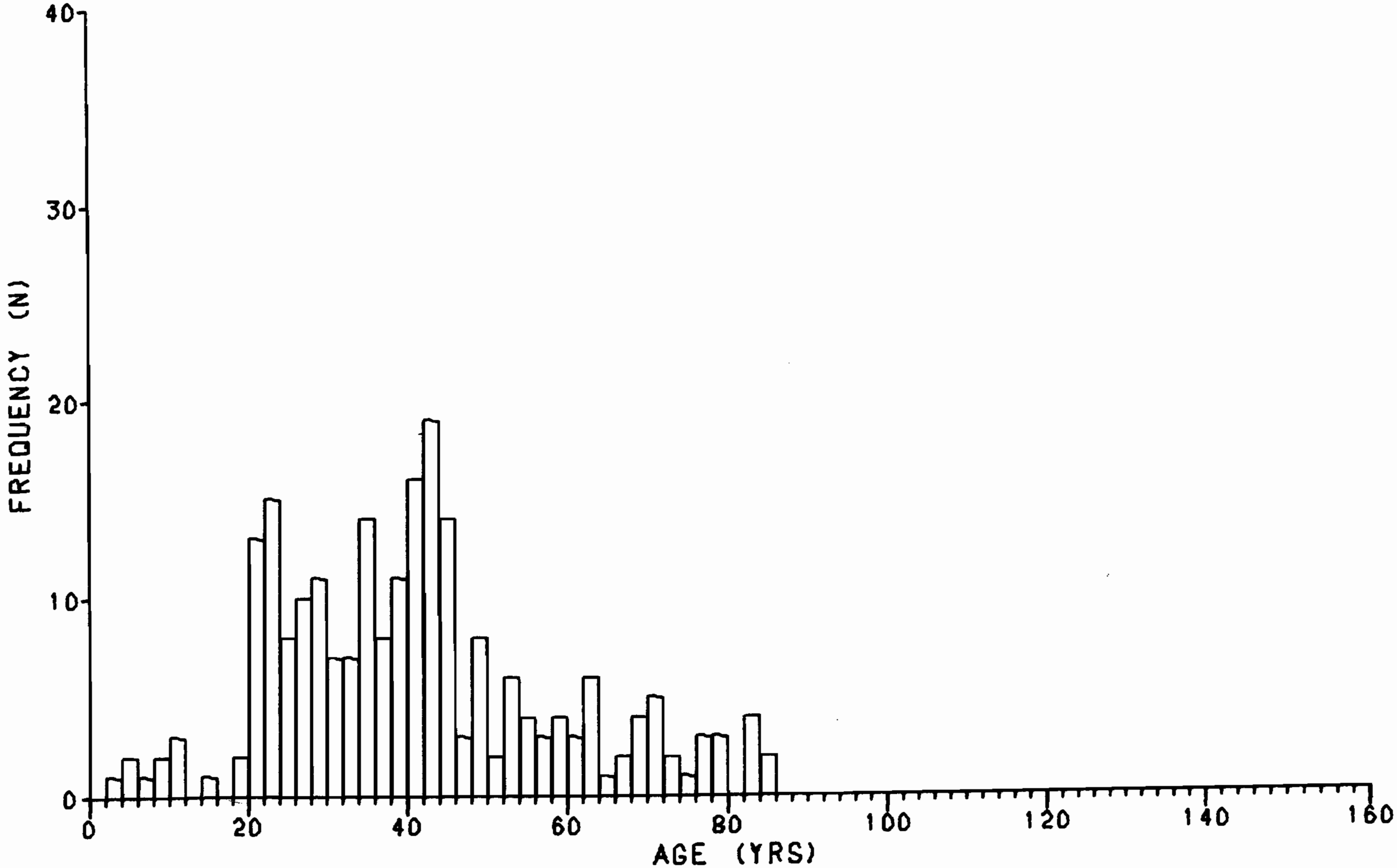

Fig. 12. Plot of age frequency, James Island, September 27, 1981.

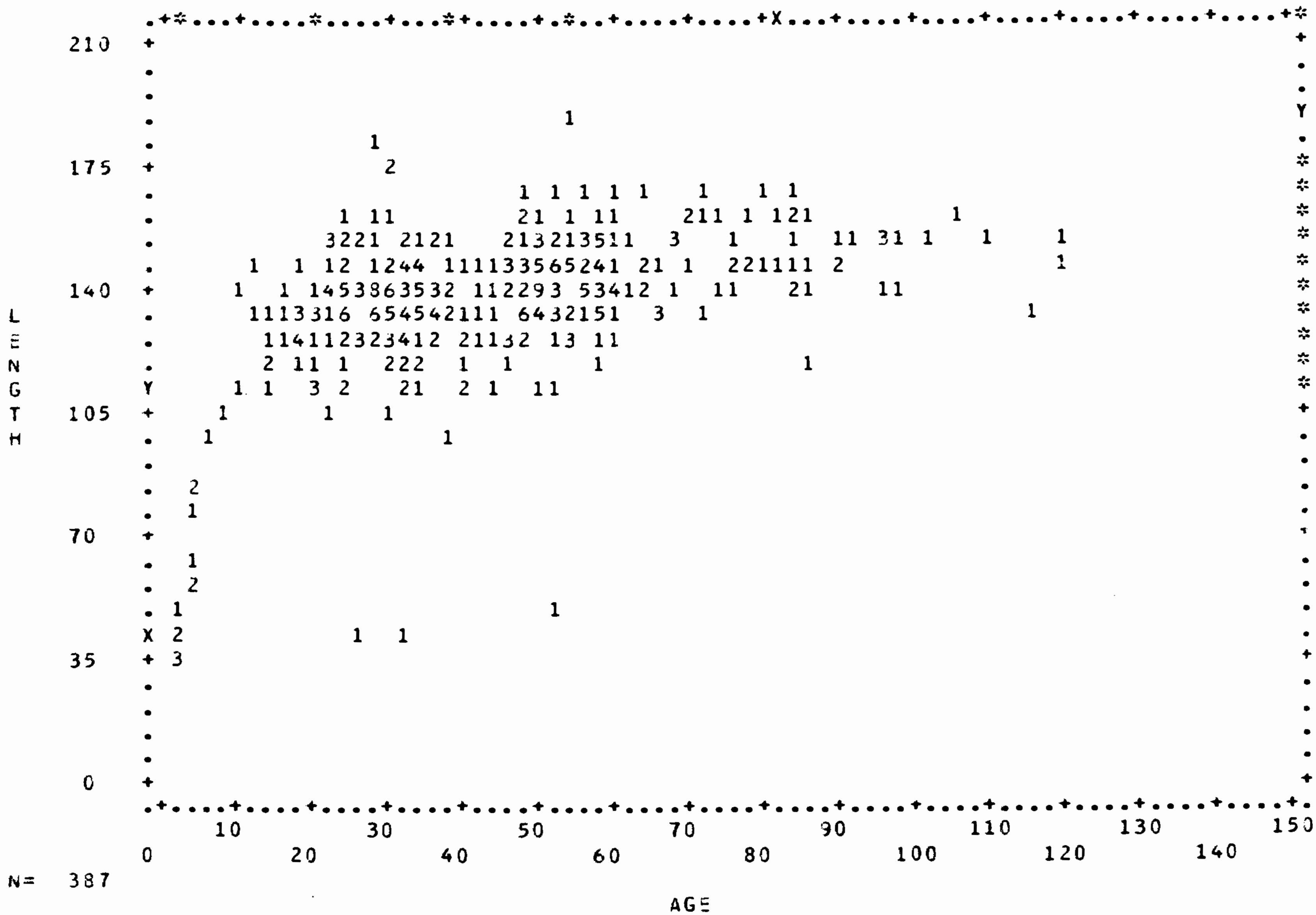

Fig. 13. Plot of length vs age, Brady's Beach, September 9, 1981.

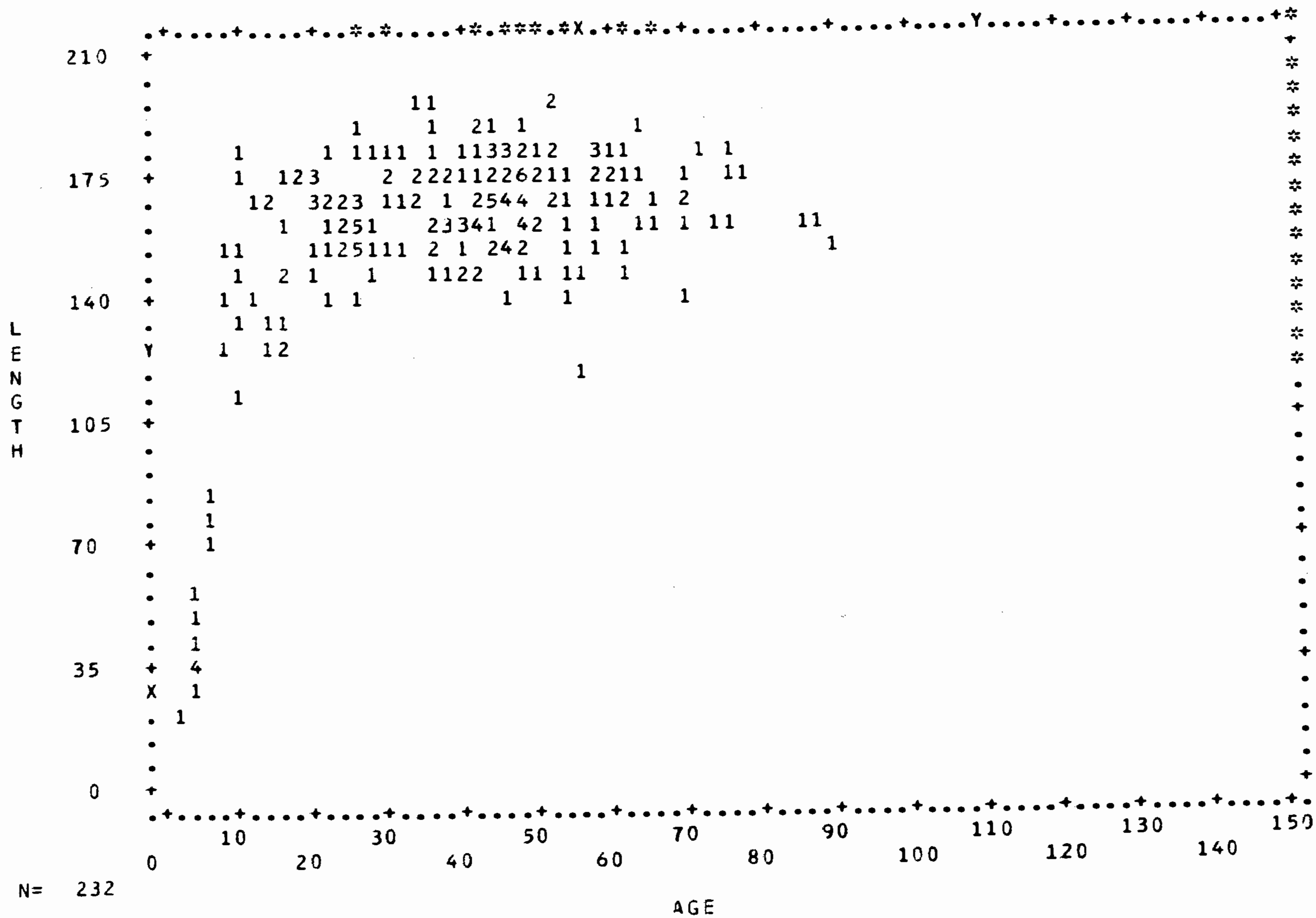

Fig. 14. Plot of length vs age, Sibell Bay, November 15, 1981.

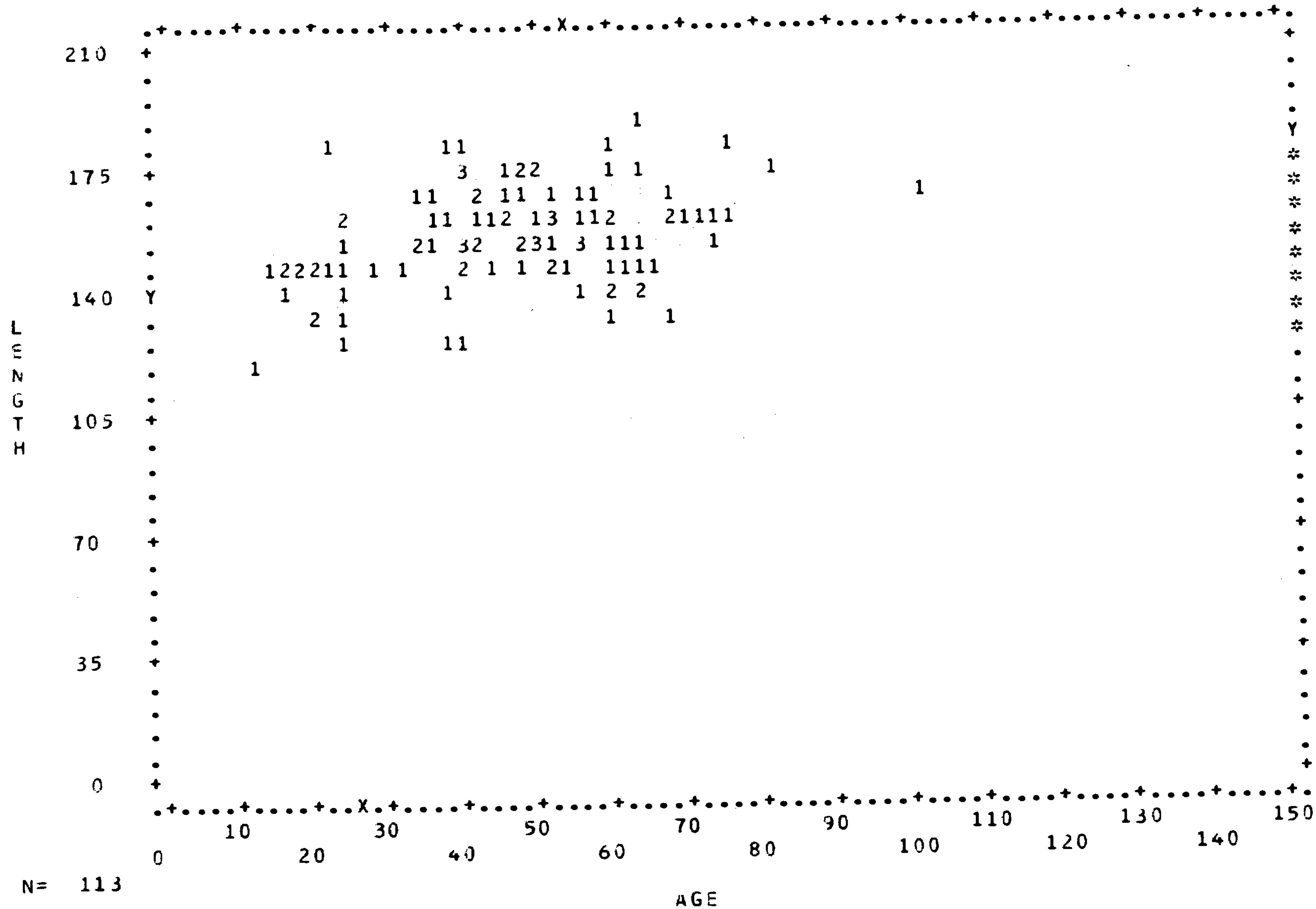

Fig. 15. Plot of length vs age, Comox Bar, October 16, 1981.

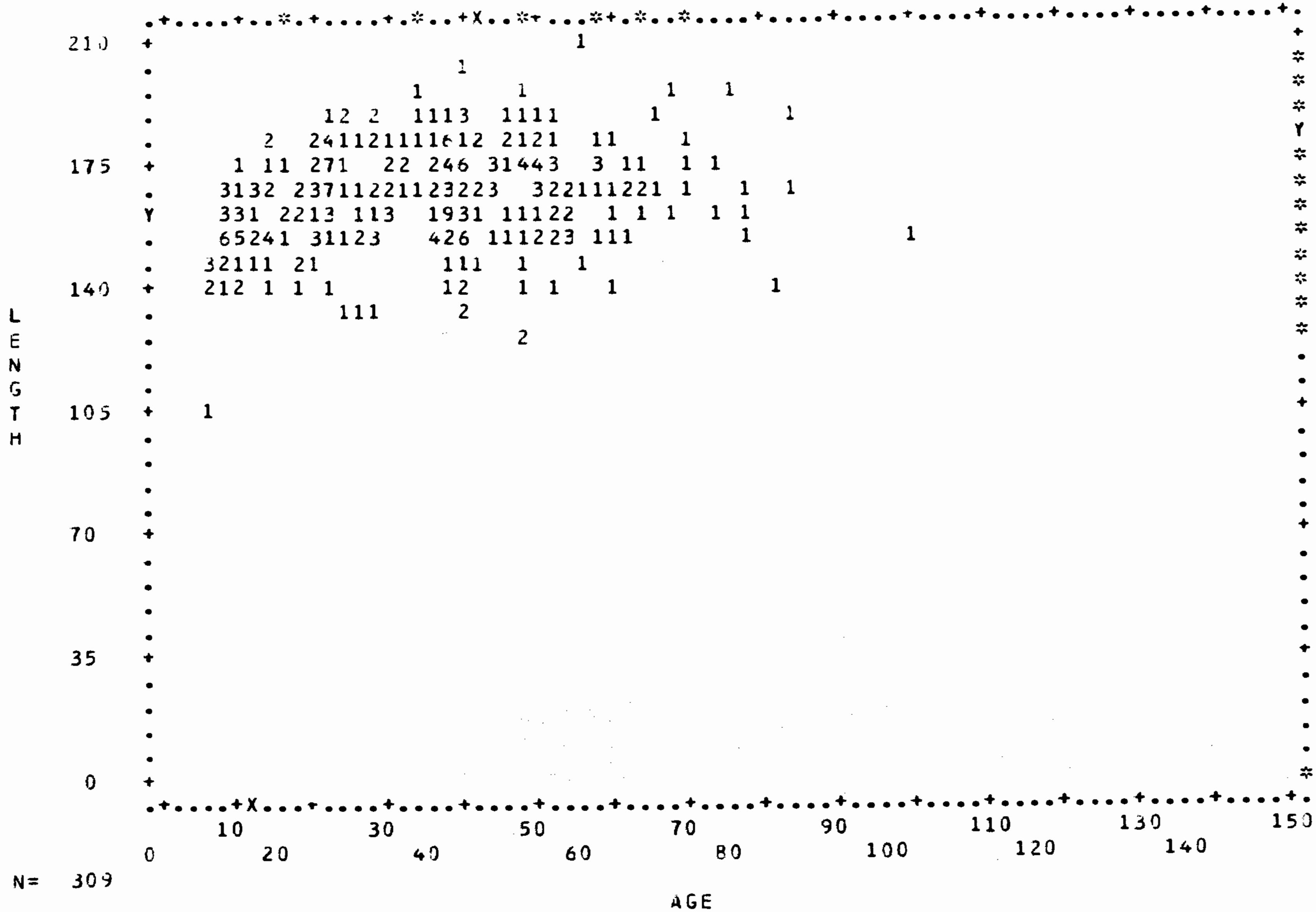

Fig. 16. Plot of length vs age, Elbow Bay, November 7, 1981.

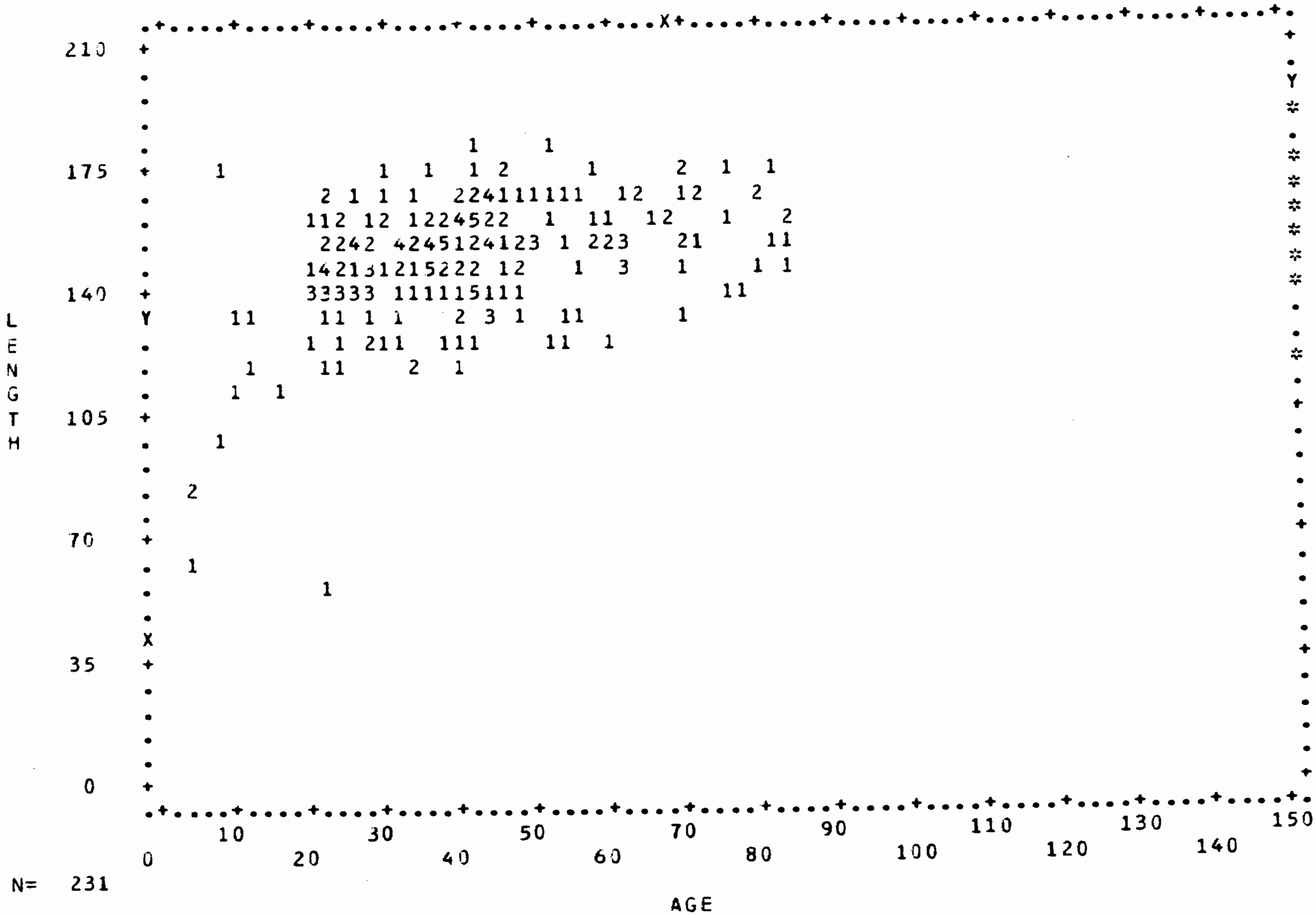

Fig. 17. Plot of length vs age, James Island, September 27, 1981.

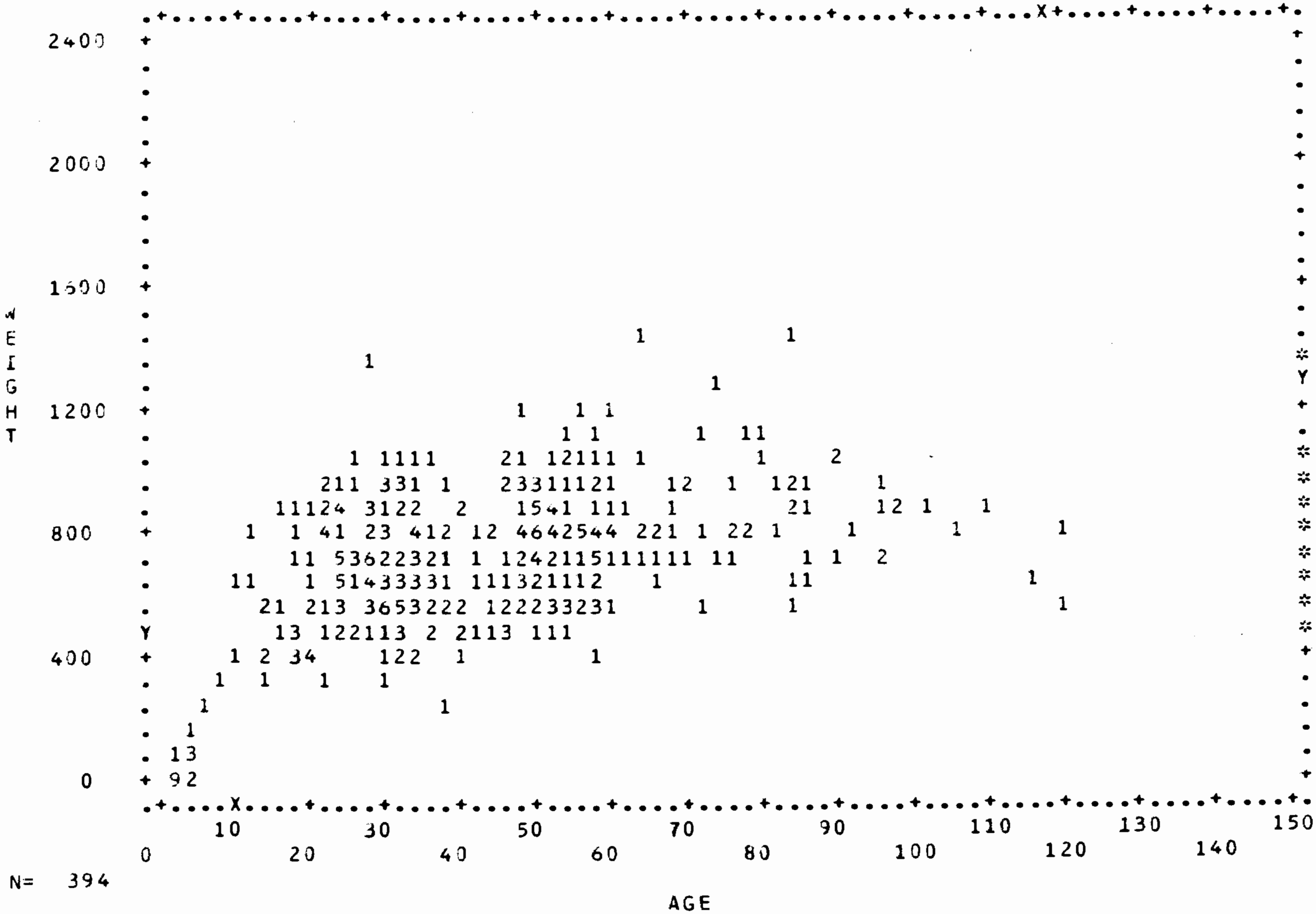

Fig. 18. Plot of weight vs age, Brady's Beach, September 9, 1981.

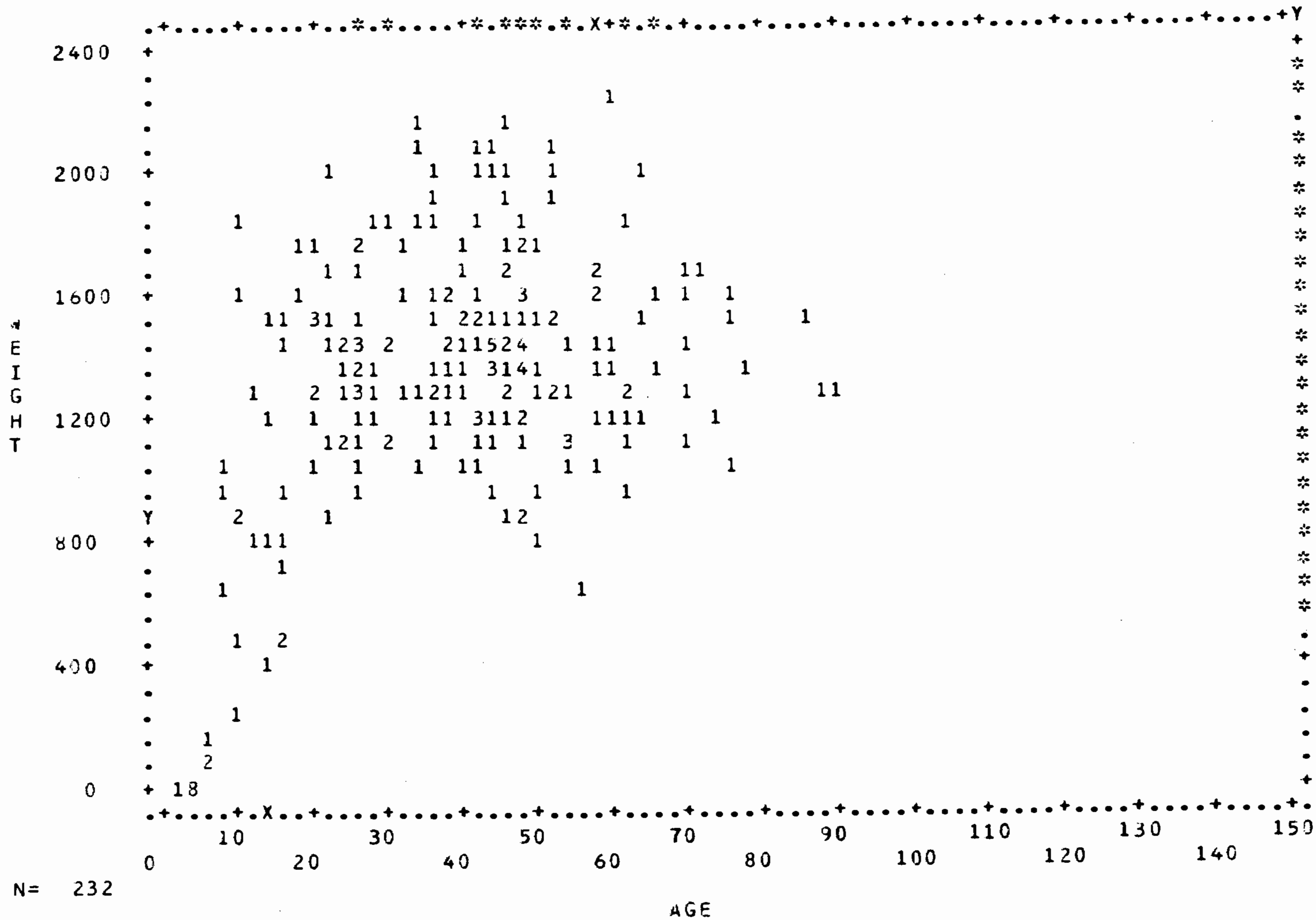

Fig. 19. Plot of weight vs age, Sibell Bay, November 15, 1981.

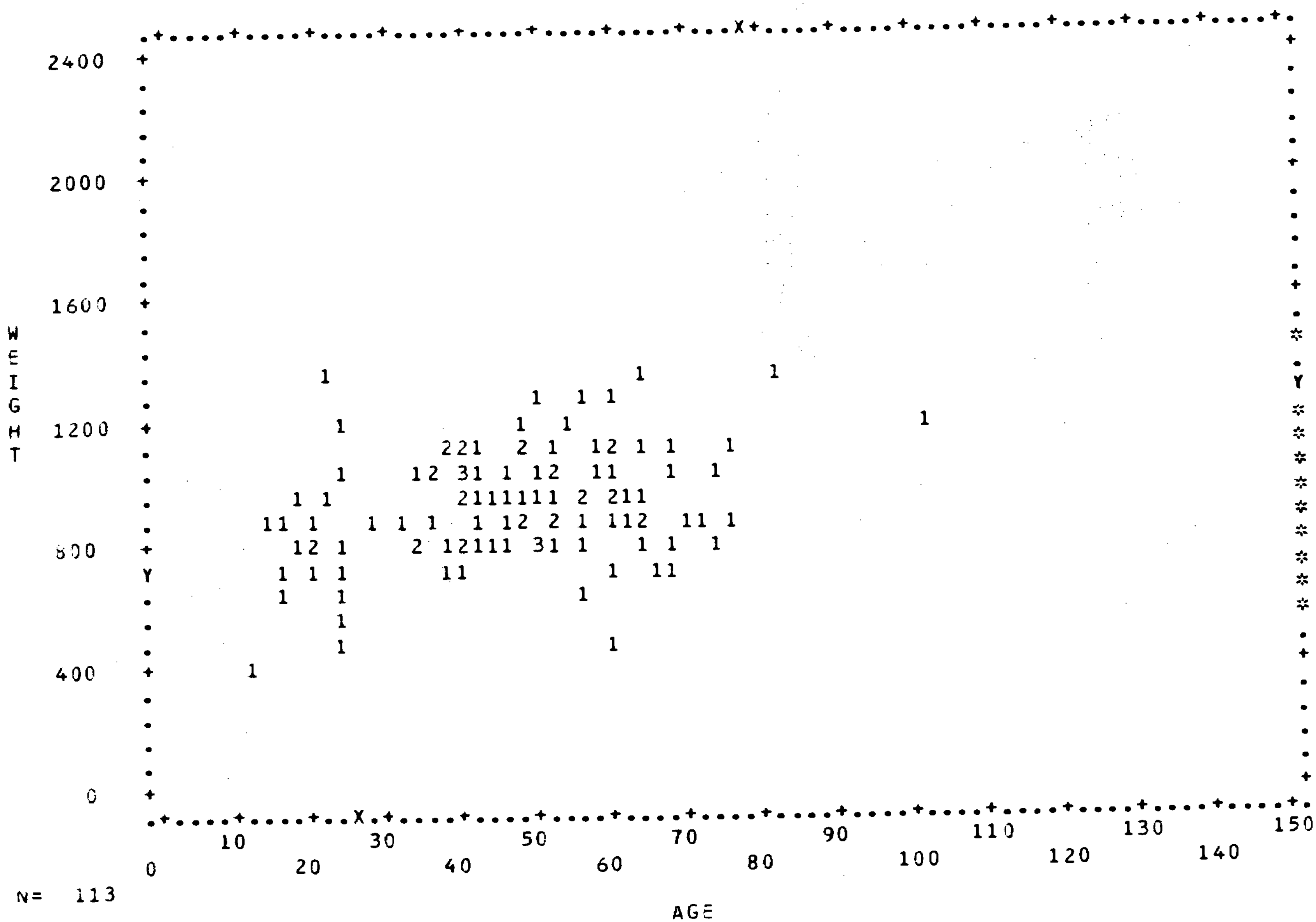

Fig. 20. Plot of weight vs age, Comox Bar, October 16, 1981.

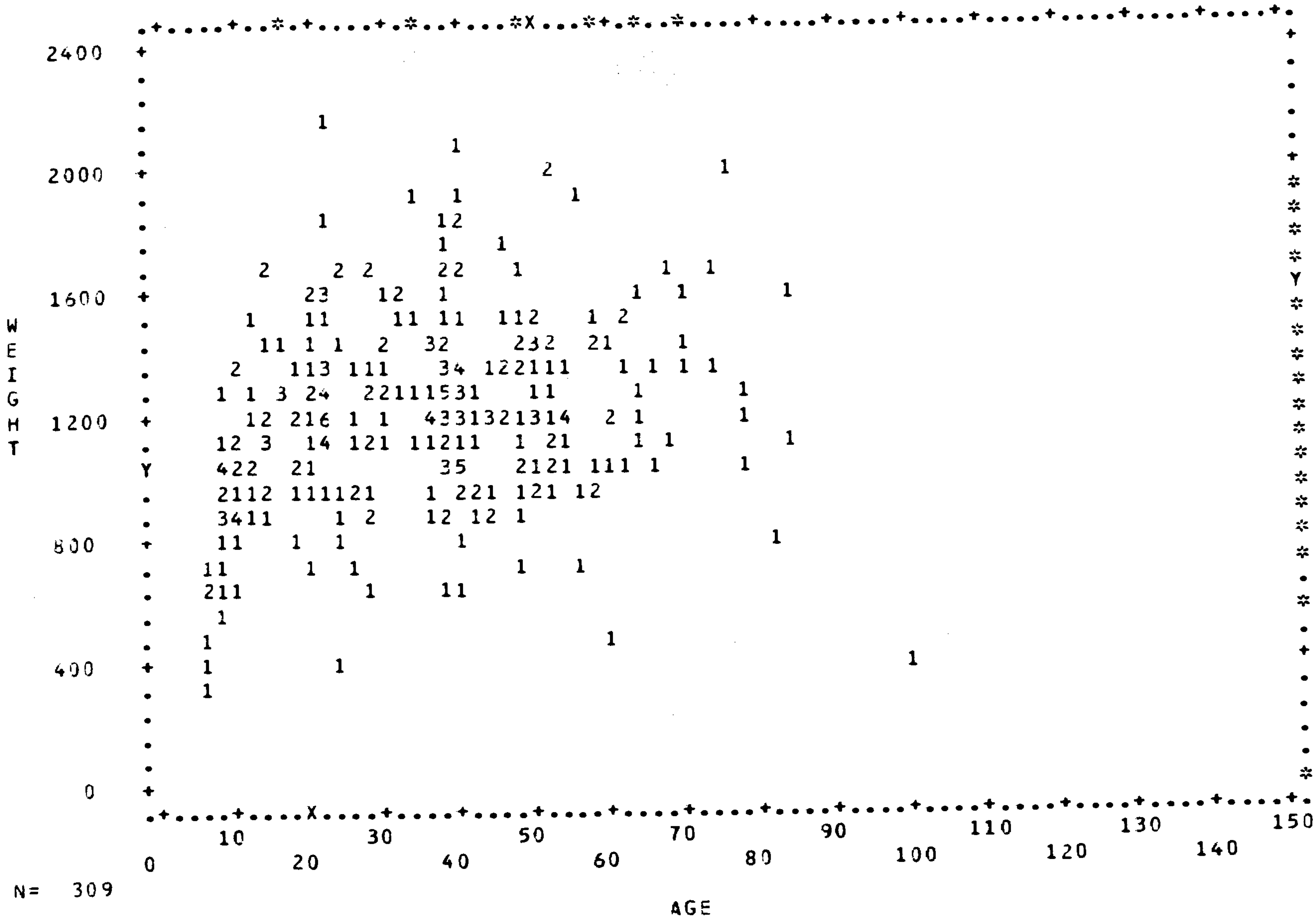

Fig. 21. Plot of weight vs age, Elbow Bank, November 9, 1981.

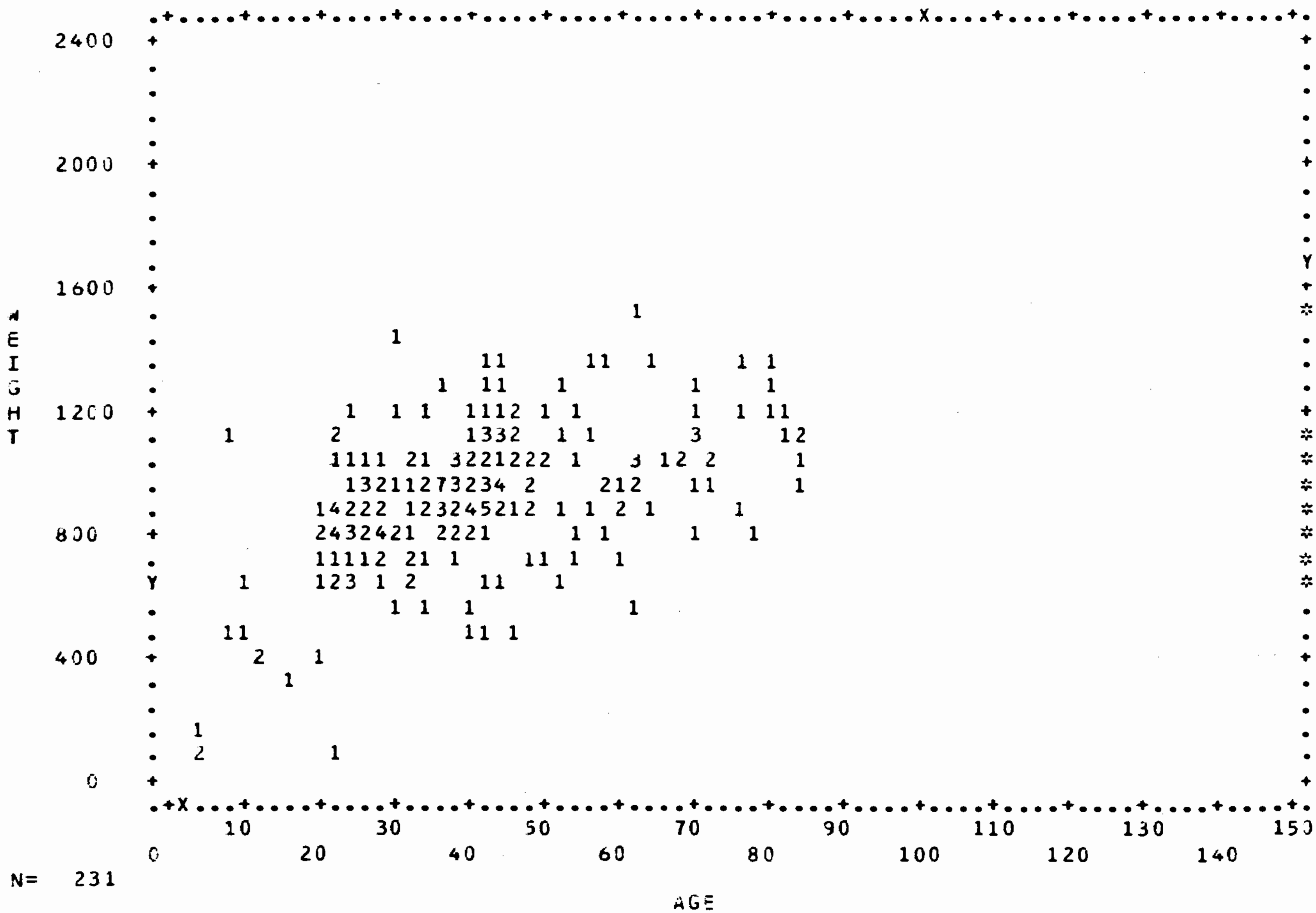

Fig. 22. Plot of weight vs age, James Island, September 27, 1981.

APPENDIX 1. DESCRIPTION OF THE FIVE STUDY SITES.

Brady's Beach (Barkley Sound) 48 49 45 N; 125 09 17 W
Dates sampled: October 7-12, 1981
Depth of Sample Plots: 7.0 m below chart datum.

Substrate: Fine sand with slight convolutions caused by the swell action. Slope less than 10%. Dense shell layer approximately 0.5 - 0.6 m below substrate surface.

Flora & Fauna: Beds of Eudistylia vancouveri on the shore side of the geoduc bed. A variety of flat fish were attracted by the sampling. Included were Pacific sand dabs and turbot. Also hermit crabs (Pagarus spp.) and a few sea pens (Ptilosarcus gurneyi).

Geoducs: Extensive bed. Some siphons (22%) were visible but they were not extended far above the sand bottom.

Sample Plots: 3 plots were placed parallel to the beach with approximately 2 meter spacing. The corner stakes of 12 mm metal re-bar were flagged with red flag tape and left for further use.

Total Area Sampled: 2 sampled plots 30 m^2 s 2 = 60 m^2

Sibell Bay (Ladysmith Harbour) 48 59 27 N; 123 46 41 W
Dates Sampled: November 14-19, 1981.
Depth of Sample plots: 4.3-7.0 m.

Substrate: Course sand on fine sand and silt (shell layer 0.5 - 0.6 m below substrate surface), slope of 20°. Bottom covered with a variety of debris including bark, logs and oyster shell. 30% of bottom covered with debris.

Flora & Fauna: Bottom fairly barren. Horseclams (Tresus spp.) in shallow region of sampled area (i.e. less than 4.3 m). Understory of Agarum sp. and Laminaria sp. less than 10%. A few Metridium senilev bryozoans and encrusting sponges associated with the logs. Large bloom of Aurelia observed. Some Cancer magister, Cancer productus and assorted flat fish were attracted by the digging.

Geoducs: 57% of the geoduc siphons were extended well above the substrate. Geoducs were fairly deep (0.8 - 1.2 m). Shell layer at approximately 0.5 - 0.8 m.

Sample Plots: 4 plots were arranged side by side with 2 m spacing. Only 3 were sampled. Corner stakes were left for further use.

Total Area Sampled:	Sample plots:	90 m^2
	Outside plots:	790 m^2
	TOTAL:	880 m^2

Comox Bar 49 39 40 N; 124 51 51 W
Dates Sampled: October 14-19, 1981.
Depth of Sample Plots: 7.0 m.

Substrate: Course sand and flat.

Flora & Fauna: The bar at this site was relatively barren with the exception of some patches of *Zostera marina*.

Geoducs: Signs of commercial digging.

Sample Plots: 4 sample plots were arranged side by side with 2 m spacing.

Total Area Sampled:

	Sample plots:	120 m^2
	Outside plots:	2050 m^2
	TOTAL:	2170 m^2d

Elbow Bank (Clayoquot Sound) 48 12 13 N; 125 56 09 W
Dates Sampled: November 7-12, 1981.
Depth of Sample plots: 5.0 - 7.6 m.

Substrate: Course sand on entire bank. Bank is level, then at approximately 4.3 m it slopes steeply to 30%. Heavy shell layer at approximately 0.8 m below sand surface.

Flora & Fauna: Eelgrass at 43 m with geoducs and horseclams (*Tresus* sp.). Below that, along the slope, there were intermittent patches of sea pens (*Ptilosarcus gurneyi*). Geoduc bed without horseclams below 4.3 m. Large number of *Cancer magister* attracted by digging operations.

Geoducs: All of the geoducs were deep (0.8 to 1.2 m). Heavy shell layer made digging difficult. Signs of commercial geoduc digging present.

Sample Plots: 4 plots were arranged perpendicular to the slope of Elbow Bank with spacing of approximately 2 m. Corner stakes were left for further use.

Total Area Sampled:

	Plots (4):	120 m^2
	Outside:	950 m^2
	TOTAL:	1070 m^2

<u>James Island</u> 48 36 45 N; 123 20 59 W
Dates Sampled: November 7-12, 1981.
Depth of Sample Plots: 5.0 - 7.6 m.

Substrate: Mud (2-8 cm deep) on sand (10-30 cm) on rock and cobble. Within shallow regions of sample area the rocks were more dense, and the rock and cobble layer closer to the surface.

Flora & Fauna: Intermittent dense clusters of sedentary polychaetes and associated foliose red algae. Also there were *Agarum* sp. and *Laminaria* spp. Overall percent cover by understory of 30%. *Cancer magister* and *Cancer productus* were attracted to the sample site as a result of sampling. Horseclams (*Tresus* sp.) were abundant as well.

Geoducs: Relatively shallow (0.6 - 1.0 m) and difficult to dig from rock and cobble. There were signs of commercial digging.

Sample plots: 4 plots were arranged side by side with 2 m spacing. Corner stakes were left for further use.

Total Area Sampled:	Sample plots (4):	120 m^2
	Outside Plots:	1520 m^2
	TOTAL:	1640 m^2