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A Comparison of Grow-Out Methods for the Bay Scallop, Argopecten irradians irradians, at Two Sites in Virginia

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A COMPARISON OF GROW-OUT METHODS FOR THE BAY SCALLOP, *Argopecten irradians irradians*, AT TWO SITES IN VIRGINIA

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ABSTRACT

Bay scallops (*Argopecten irradians irradians*) were once native to the lower Chesapeake Bay, and constituted a valuable crop in the late 1920's. Loss of natural habitat in the early 1930's preceded the virtual elimination of this species from the area. It may be possible to return the bay scallop to the Eastern Shore of Virginia through mariculture, if appropriate site and gear criteria can be determined. Hatchery-reared bay scallops of mean size 24 mm ($\pm$ 0.2) were placed into oyster bags, lantern nets and trays in three replicates each at Cheriton and Magothy Bay, Virginia, at a density of 700/m^{-2}, on August 13-14, 1991. At five points during the growout period, the enclosures were monitored for survivorship and mean shell heights and volumes were estimated. The sites were compared by measuring temperature, salinity, chlorophyll-a abundance and current speeds. Harvests of all scallops in the enclosures of one replicate (i.e., one tray, oyster bag and lantern net) at each site were made at 98, 121 and 186 days; shell heights measured and subsamples of size n = 50 from each enclosure evaluated for muscle and non-muscle tissue masses and degree of epibenthic fouling. The Cheriton (bayside) site was found to be more appropriate for bay scallop mariculture due to the slower currents, consistently adequate food supply and warmer temperatures. While the scallops grown in trays grew to market size about two weeks faster than the other gear types, an analysis of relative economics reveals that the oyster bags were the most cost effective. Oyster bags also proved the most reliable of the gear types tested. Overwintering affected only the lantern nets in Magothy Bay, which gave these slowest growing scallops a chance to 'catch up.' A pilot-scale study is now required to fully determine the economic feasibility of using oyster bags on the bayside of Virginia's Eastern Shore.

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INTRODUCTION

The bay scallop, *Argopecten irradians irradians*, is a native species of Virginia which was commercially harvested until the 1930's, when it disappeared along with much of its eelgrass habitat, according to Orth (1978) and Castagna and Duggan (1971). Due to the continuing loss of submerged aquatic vegetation in the Chesapeake Bay (Alliance for the Chesapeake Bay 1989; Orth 1978), this bivalve is not likely to return to harvestable levels in the near future. It has been shown by several workers, e.g. Castagna (1975), Rhodes and Widman (1980), however, that it is biologically feasible to spawn *A. irradians irradians* in the laboratory and cultivate it in an enclosed area, which protects against predators and simplifies the harvest.

The return of the species to commercial status in Virginia via mariculture is enhanced by several factors. The size and location of natural populations vary from year to year (Middleton 1983); the Food and Agriculture Organization of the United Nations (FAO) landings records show a fluctuation of as much as 62% between consecutive years in the last decade (Anon. 1986, Anon. 1990). Bay scallops have a relatively high market value-- NMFS reports a harvest of 539 thousand pounds in 1990, worth $3.1 million in ex-vessel prices (NMFS 1991). They are short-lived and highly fecund (Risser 1901; Belding 1910a; Belding

1910b; Gutsell 1928), and cultured growth to a marketable size (40 mm minimum shell height) has been demonstrated within a single season for the warmer climes of Virginia (Castagna 1975; Castagna and Duggan 1971; and Duggan 1973), North Carolina (Gutsell 1928) and Georgia (Heffernan *et al* 1988; Heffernan *et al* 1992). The cost for hand shucking labor adds a prohibitively high expense for aquaculturists (who have already made a large investment in gear); this can be overcome by marketing the animal as a whole product (DuPaul pers. comm.). These factors taken together could mean a fairly quick return on an investment in bay scallop farming.

A fisheries biologist in Massachusetts, David Belding, looked closely at bay scallops in the early 1900's, and concluded it was a resource worth encouraging for mariculture (Belding 1910). Since Belding's time, important efforts have been made towards developing bay scallop mariculture methodology, the basis of which are details of its life history (Risser 1901; Belding 1910a; Belding 1910b; Gutsell 1930; Loosanoff and Davis 1963; Marshall 1960; Marshall 1965; Sastry 1961; Spitzbergen 1979). Thorough synopses of this information are provided by Fay *et al* (1983) and Broom (1976).

The biology of spawning and raising *A. irradians irradians* has been explored by many workers-- Castagna (1975), Castagna and Duggan (1971), Castagna *et al* (1971), Rhodes and Widman (1980) and Foster (1990) describe in detail the processes of spawning the bay scallop-- which is currently being commercially practiced at least by Mountain Island in Nova Scotia, Canada, Taylor Industries in Massachusetts and The Clam Farm in New York. Intermediate (post-set) grow-out methods include indoor flow tables (Castagna 1975), outdoor raceways (Rhodes *et al* 1981; Middleton 1983; Tettelbach 1988), upwellers (Foster 1990), pearl nets (Rhodes *et al* 1981; Middleton 1983), and trays (Castagna and Duggan 1971). Seed (14 mm shell height) can be purchased for about $30/thousand from commercial growers (April, 1991). Juveniles have been deployed increasingly in the last thirty years for enhancement of natural stocks in Waterford, Connecticut (Morgan *et al* 1980), Rhode Island (Russell 1973), currently in Long Island Sound (Malinowski pers. comm.; Rhodes *et al* 1981), Martha's Vineyard in Massachusetts (Matthiessen and Toner 1966; Gates *et al* 1974; Walsh 1981; Kelley 1985), and St. Lawrence, Canada (Townshend and Worms 1983). At least the latter three stocking programs are extant (Malinowski, pers. comm., Mountain Island, pers. comm.).

The process of grow-out to market size has been explored using several different methods on the Eastern seaboard, and includes placement in pearl nets (Heffernan *et al* 1988; Foster 1990; Walker *et al* 1991), lantern nets (Rhodes *et al* 1981; Rhodes and Widman 1980; Middleton 1983; Graham 1984; Foster 1990), 'clam-style' sunken beds (Skip Kemp pers. comm.), suspended, floating and bottom trays (Castagna 1975; Castagna and Duggan 1971; Castagna *et al* 1971; Duggan

1973), and pens (Castagna 1975; Castagna and Duggan 1971; Castagna *et al* 1971). Grow out in two different environmental regimes ("exposed" vs. "unexposed") was also examined by Heffernan *et al* (1988) in Georgia.

The development of a whole-scallop marketplace has proved to be a critical turning point for bay scallop growers. Prices for shucked bay scallop adductors (approximately $10/lb) cannot bring an adequate return of a mariculture operation's investment in gear and labor, whereas selling them whole (at around $0.25 each) does by reducing the cost of labor for shucking (Rodman Taylor, pers. comm.; William DuPaul, pers. comm.). The introduction of a shell-on product has been successful in north-eastern Canada , Massachusetts and most recently, in Virginia. Consumer acceptance of a shell-on product has been excellent for both the restaurant and shellfish markets in Canada (Mountain Island, pers. comm.) and Massachusetts (Rodman Taylor, pers. comm.), and in restaurant trials in southern Virginia (William DuPaul, pers. comm.). According to Dr. William DuPaul (pers. comm.), bay scallops still in their shell have their present appeal in Virginia in a "white table cloth" market, i.e., 'upscale' restaurants. The price commanded by whole, cultured scallops is apparently adequate to sustain commercial operations in both Canada and Massachusetts; the development of an "upscale" market in Virginia may make the economic return for a shell-on product adequate to support mariculture ventures here as well. The advantage of a single season grow-out period would place Virginia at a competitive advantage over the other two locations at least because of reduced labor costs.

Still, with all this ground work done, the field has yet to fulfill its potential in Virginia. While the problem of prohibitively high shucking costs is being overcome by the formation of a whole-animal market, the successful development of an efficient methodology for the warmer, shallower waters of the lower Chesapeake Bay has been elusive. Gear and site selection are two important factors in the solution to this problem. This study made side-by-side comparisons at two shallow (1-2 meters) sites: Magothy Bay on the seaside and King's Creek in Cheriton on the bayside of Eastern Shore using three final grow-out methods: off-bottom trays and oyster bags, and suspended lantern nets.

This work was undertaken to provide bay scallop culturists with information on the cost-effectiveness of materials, the appropriateness of site locale, and the relative efficiency of three enclosure types. The optimization of animal growth might tip the balance in favor of profitable commercial grow-out. At the very least this examines the unexplored potentials of both the seaside of Virginia's Eastern Shore and the oyster bag, and gives researchers a new look at the problems and possibilities of farming Virginia's inshore waters in the Nineties.

MATERIALS AND METHODS

One bag, tray and lantern net were placed as a group at each of three subsite locations on a site. The perimeters of neighboring subsites were within 1.5 meters; the sites were separated across the land barrier by a northwest/southeast distance of about 19 kilometers. Bags and trays were placed on racks (after Mountain Island 1990), while lantern nets were buoyed from concrete anchors. The enclosures were placed 1 meter apart in a line, in the order of bag-tray-net. The complete array of racks and nets at each site was configured to put the longitudinal axis perpendicular to the major tidal current flow. The location of each site was selected for environmental homogeneity among the subsites (current exposure, depth of water column and substrate quality), coverage at the lowest tides, accessibility and protection from human interference. White buoys served as position markers and helped reduce boat traffic in the immediate vicinity. One rack held either one tray or one bag across the top. Stocking density was 65 scallops ft^{-2}, based on reports primarily from Duggan (1973), but also considering Rhodes *et al* (1981) and Rhodes and Widman (1980).

At each of three harvests in November, December and February, the difference in growth between the three enclosure types at two sites on Virginia's Eastern Shore were examined by comparing final wet weights of muscle (adductor and abductor combined) and non-muscle tissue (all other tissues combined), shell height and volume; shell fouling was also gauged. Changes in survivorship, volume-per-scallop and shell height were monitored during growout, as were site physical parameters (temperature, salinity, chlorophyll-a and current speed). So as not to obscure the effects of natural attrition, sacrificial sampling was saved until the end of the experiment. The sampling schedule for the biological and environmental variables is presented in Appendix 1.

The Gear

The polyethylene 'oyster bag' from ADPI is actually a rectangular box measuring 87.6 x 44.4 x 8.9 cm (all enclosure dimensions are internal), and has 14 mm square mesh. The 88 x 45 cm rack was made of fiberglass reinforced plastic (FRP); the 1 m legs were sunk 60 cm into the mud and shell sediment. Three bungee cords woven through the bag's bottom mesh held it onto the rack. Each of the three replicate bags at each site were stocked with 436 animals. (See Figure 1.)

Preformed polyethylene 'Cherrystone Farm' trays are 112.4 x 79.0 x 8.9 cm; the sides are solid while the bottom has 4 mm square mesh. A 14 mm square mesh screen was fitted across the top of the tray and held by extruded plastic clips. A 113 x 79 cm FRP rack supported a tray on 1 meter legs and was also sunk 60 cm (as above). Three bungee cords strapped over and three under held the tray onto the rack. Each tray initially contained 859 bay scallops. (See Figure 2.)

Four tiered polyethylene lantern nets with mesh size of 14 mm have a diameter of 50 cm and single tier height of 20 cm, and come from Taylor Seafoods International. The net was suspended between a buoyed line and an 80 lb concrete anchor. The bottom tier of a net hung a maximum of 35 cm above the bottom, clipped onto the anchor's stainless steel U-bolt with a stainless steel carbine. The 4-tier nets were cut from stock 10-tier nets and re-assembled using polypropyline and nylon line. The four-tiered nets contained 137 scallops per tier for a total of 548 scallops per net. (See Figure 3.)

The Sites

The bayside site is located in Cheriton, Virginia, in 1.6-2.2 m of water *ca.* 150 m off shore from Cherrystone Farms. The 2-3 cm thick black mud substrate supports algae (primarily eelgrass), branching bryozoans and sponges. Between the site and the shore are marsh, some small tidal flats, and an area utilized for the cultivation of the hard clam, *Mercenaria mercenaria*. The seaside location is in Magothy Bay, which is south-southeast to Cherrystone. The water there is 1.7-2.3 m deep about 400 m from the marsh shoreline. The 0.5-1.0 cm layer of black mud on top of clastic grey sediments supports little infauna, save an occasional sponge. (See Figure 4.)

Sampling Methodology

Surface temperature and salinity were checked eight times with a mercury bulb thermometer and a temperature-compensating refractometer, respectively (Appendix 1).

Determination of chlorophyll-a levels followed the regimen described by K. Webb (pers. comm.). The either 5 or 10 ml water sample for chlorophyll-a (chl-a) detection was drawn from approximately 5 cm below the surface and filtered in the field through a Whatman GF/F filter. While still in the field, the filter was placed into a blackened test tube with 8 ml of extraction fluid: 45% acetone, 45% dimethylsulfoxide (DMSO), 10% de-ionized water. Chl-a concentration was measured on a Turner's Designs fluorometer within one week of drawing the sample. Hourly samples were taken over a full tidal cycle to address the effect of tidal influences on chl-a abundance. Sampling was performed at three points during the experiment: at deployment, five weeks following, and just prior to the first harvest. Because the bay scallop is a broad spectrum filter feeder, this measurement is not wholly adequate to estimate complete food availability. It does, however, provide a good basis of comparison for the two sites. Kirby-Smith and Barber (1974) and Rhodes *et al* (1981) used chlorophyll-a concentrations to estimate food availability and firmly linked concentration to bay scallop growth.

Four attempts to measure current speed were made, yielding one full set of data (sudden bouts of bad weather and equipment failures deterred three attempts).

The data was acquired by S-4 current meters deployed simultaneously at Cheriton and Magothy Bay on 01 October, 1991. The instruments were placed 5 meters away from and perpendicular to the middle subsite, about 40 cm off the bottom. They recorded data for at least a full tidal cycle (twelve hours) in ten minute intervals under skies that had been clear for several days.

To establish whether the growth of the animals was a linear function of time, volumetric and length data were recorded at the time of stocking and harvest, and at five points in between. Growth estimated by increases in shell height would literally have taken days to measure if calipers had been used in the field--instead, two alternatives were employed: volumetrics and digitized hole punches, the latter of which was developed for this study. As opposed to measuring 1800 shell heights with vernier calipers each time, the volumetric method has been recommended by Mike Castagna and Jim Widman (personal comm.), and by Ed Rhodes (Rhodes *et al* 1981) as a time saving strategy. The number of scallops required to make a liter was estimated by graduated cylinder; all the scallops in the enclosure were measured in this manner so as to a) give the best estimate, and b) make handling stress uniform. The mean of all such measurements for each bag, tray and tier was used to chart volumetric growth. While volumetric sensitivity to changes may or may not be as good as with height measurements, it needed only to provide an adequate basis for comparison. The method's draw back, however, is that the fouling encountered on the Eastern Shore may diminish accuracy because growth of shell fouling organisms is inseparable from the growth of the scallop itself; the fouling type and growth rate will limit the comparability of measurements made in this study to other work done in the same geographic area.

Shell height measurements were also made to make possible comparisons of growth rates from other studies and for methodological contrasts with the volumetrics. It is critical to employ a fast way of doing this in the field so as to minimize handling and desiccation stresses. Using waterproof paper, a hole was punched at the opposite end of a scallop butted onto a measuring board. (See Figure 5.) The holes in the paper were subsequently read with a digitizer (Numonics Electronic Calculator) directly into a database management program (Minitab). Sample size ranged from a one third of the enclosure's live scallops to a maximum of 60, depending on survivorship at the time of sampling.

Fouling was estimated by eye based on percent coverage on the right valve. It was deemed "low" if coverage was between 0 and 33%, "moderate" if between 34 and 67% and "high" if greater than 67%. Designated values for the purposes of statistical analysis were 1, 2 and 3, respectively.

At the time of each harvest, samples of n=50 scallops from each enclosure were shucked and muscle (adductor with abductor) tissue separated from the other tissues. The wet weights of these two tissue groups were measured to the nearest tenth gram on an OHAUS electronic scale.

Fouling of unit exteriors by macrophytic algae, sponges, bryozoans, etc. was controlled by brushing when necessary. On the bayside, tray tops and lantern nets were each brushed once, while the oyster bags were cleaned off twice. Seaside bags were cleaned on four occasions; lantern nets were scrubbed thrice. (Early tray loss on the seaside precluded cleaning of those units; see below.)

Scallop Rearing

Twenty-two mature *Argopecten irradians irradians* were induced to spawn by thermal stress (after Castagna and Duggan 1971) on a flow table in Wachapreague, Virginia, on April 16, 1991. Approximately 229,000,000 fertilized eggs were produced. The larvae were held in fiberglass enclosures with running filtered seawater. Random culling reduced the population to about 250,000 with a mean diameter of 1.5-2.0 mm by 20 May, 1991. The spat grew to about 2 mm in 6 weeks, they were then transferred to upwellers at Cherrystone Farms in Cheriton, Virginia. The 10°C water temperature was unusually high for that time of the year. The scallops had a mean size of 3.5 mm and 5.25 mm on the 11th and 20th of June, 1991, respectively. By the latter date, subsequent (random) cullings had further reduced the number of animals to about 30,000. A portion of these were used for a separate study involving a single grow-out strategy and the remaining scallops used in this research.

Intermediate grow-out methods follow those at the Connecticut NMFS laboratory (Rhodes and Widman 1980) and The Clam Farm on Long Island Sound (Malinowski, pers comm). Animals passed through a 12 mm screen and caught on an 8 mm screen (mean shell height = 11.25 mm, n = 100) were placed into intermediate grow-out enclosures on 18 July, 1991, at the Cheriton site. Three 4 mm mesh oyster bags and three trays covered with 4 mm mesh were used for intermediate grow-out. Intermediate stocking density was approximately 3300 m^{-2}.

The day prior to placement into the final grow-out enclosures, juveniles were again graded to further reduce shell height variability by sieving on an 18 mm polyethylene screen. Cheriton units were deployed on 13 August, 1991 under calm conditions; units in Magothy Bay were deployed the following day in the presence of white caps. Mean shell height at time of deployment was 24.0 mm ± 0.2 (n=202); an average of 149 animals were required to occupy one liter. The reason for not deploying earlier was to reduce loss from the animals falling through the lantern nets' diamond mesh, which stretches to about 22 mm. Growth data from other studies indicate that stunting does not generally occur until after about 24 mm (Jim Widman, pers. comm.; Duggan 1973; Rhodes and Widman 1980; Widman and Rhodes 1991). No gear problems were observed in an examination one week following deployment.

Stability of racks and anchors was ensured by securing them in the field (with marking buoys) on the 20th and 21st of June, 1991, well in advance of enclosure deployment. The anchors were manually maneuvered into position on each subsite. By deploying the racks three weeks prior to the enclosures, the substrate was given a chance to adhere to and seal around the FRP legs, enhancing steadiness and probably allowing adjacent air pockets to close. No problems with racks, anchors or floatation buoys were experienced at any time in the experiment. Several marking buoys (2 bayside, 1 seaside) apparently broke loose, probably due to abrasion by barnacle and oyster fouling on the nylon line.

Statistical Analysis

Examination by gear and site of fouling level and muscle and non-muscle tissue masses was made with multiple analysis of variance (ANOVA). Multiple analysis of covariance was used to determine differences in shell heights and volumes and growth rates. Time was used as the covariate to allow comparisons throughout the grow-out period. The SYSTAT statistical package was used for all analysis. Examination of differences by gear over the three harvests as well as between lantern net tiers were also made. Both the MANOVA and the multiple analysis of covariance use a cell means model for an incomplete block design, needed because of the lost gear. If differences were found at the $\alpha = 0.05$ level of significance, a Tukey HSD (Honest Significant Difference) multiple pairwise comparison test was run to discover where the departures lay. The issue of pseudo-replication between subsite replicates was examined in two ways: by a) analysis of variance of shell heights from extant gear at the last sampling point prior to the first harvest (i.e., all bayside units at 74 days and seaside oyster bags and lantern nets at 75 days); and b) by Tukey's analysis of shell height data over the duration of the experiment. There is no evidence to support the possibility of pseudo-replication between subsites at that time: analysis of variance results were $\alpha = 0.215$ and 0.762, bayside and seaside, respectively; Tukey's tests did not reject the H_o (no difference between the means), where universally $\alpha \approx 1.00$. Survival was estimated as the percentage of the initial number of animals still alive. Linear correlations between dependant variables were tested by regression analysis. Data presented in tables were compiled with the Quattro Pro spreadsheet package.

Costs

The number of hours employed in a) constructing and securing the groups of enclosures to their respective locations, b) cleaning, c) repairs and d) the harvest time was added for each enclosure type and then multiplied by a wage of $5.25/hour. This dollar amount was added to materials costs for that enclosure type. Each gear's total initial cost was then divided by it's expected number of serviceable years.

RESULTS

The harvest schedule, with notes on missing gear, is found in Appendix 12. Trays from subsites 5 and 6 (T5 and T6) were lost on the seaside between the first and second week after deployment; the remaining seaside tray (T4) was missing by the middle of the third week. Several miles of shoreline were searched after each loss as well as every 2-3 weeks following; no trace of the trays or the animals they contained ever showed up. A tray (T2) was lost on the bayside between the third and fourth week post-deployment, it was found empty two weeks later, washed ashore. A second tray (T1) was discovered empty and upside down three meters from it's rack, having been upset sometime between the 14th and 20 weeks. Two bayside lantern nets (LN1 and LN2) were missing after unusually high storm-driven tides in the 10th week; LN2 only was recovered partially intact (the second tier from the top was empty). That net was returned to it's anchor with fresh (though doubled) anchor line. Seaside tray loss was probably due to high current speeds lifting the unit up and subsequently rocking it out from it's bungee cords. Bungee cords remaining on empty tray racks (about half of the cords deployed) showed mild abrasions. The bungee cords found on and around the racks used for bayside trays were severed, probably from abrading against the shell-fouled tray sides; on three occasions fraying or broken bungee cords at this site were replaced in an effort to prevent losses. Loss of the bayside lantern net at subsite 2 (LN2) was caused by abrasion of the line connecting the stainless steel carbine to the net (the net was recovered with frayed anchor line and the carbine was still clipped to the anchor). The cause for the loss of LN1, however, is ambiguous, as only the anchor and marking buoy remained; no sign of the carbine, net fragments, loose scallops, etc., were ever found. This leaves tampering as the probable reason.

The Sites

The sites were significantly different in all the parameters measured, changing through time in a more-or-less parallel fashion. The first aspect in which they differed was in the amounts of available chlorophyll-a (Figure 6). The overall mean chlorophyll-a measurement for the bayside and seaside were 17.2 and 3.71 μg/L, respectively.

Figure 7 shows the currents on the seaside were faster than on the bayside. The mean for Magothy Bay was 11.2 cm/sec, while Cheriton was 3.9 cm/sec, again, an order of magnitude difference.

The seaside site had a generally higher salinity and lower temperature during the study period (Figure 8). Salinity was not likely to have been very important in this study: principal component analysis (PCA) indicated that salinity accounted for about 10.3% of the variance in survivorship on the bayside, and was not an associated factor at all on the seaside. Temperature, however, explained 87.3 and

84.6% of the variance in survivorship on the bayside and seaside, respectively. This close degree of association, however, may simply have been due to the coincidence of declining temperature and survivorship. Salinity accounted for 9.0 and 13.8% of the variance in growth on the bayside and seaside, respectively. The role temperature played in shell height changes, however, could not be accurately determined using PCA. Results of PCA for growth rates were also indeterminate.

Multiple analysis of variance and covariance (MANOVA and MANCOVA, respectively) revealed a difference between the sites in all the variables measured (Appendix 3). Tukey's Honest Significant Difference tests showed further that the bayside bay scallops had larger shells and tissue masses; they grew faster, were more heavily fouled and had greater shell volumes (Appendices 4 through 9).

The Gear

The following references to lantern nets pertain to each net as an aggregation of tiers. Tier differences within the nets are addressed separately in Appendix 2.

Significant differences were found between each gear type within a site at each harvest, except for seaside fouling (Appendices 3-8). Additional Tukey's tests found that the trays had scallops with the largest mean shell height, with those in oyster bags second and scallops in lantern nets third (Appendix 4 and Figure 9a). The tray-grown animals had the largest muscle masses, those from the other two gear types were not found to be different (Appendix 6). Non-muscle tissue weights were the same regardless of gear at the bayside site (Appendix 5). At the seaside, animals in oyster bags grew heavier non-muscle tissues than those in lantern nets. The mean volume of scallops was larger in trays than in lantern nets and the same as the oyster bags (Appendix 9). Linear correlations of pooled means were found to be appreciable between shell volume and the other variables, as well as between tissue masses and shell height (Appendix 10).

Scallops grown in trays were heavily fouled; no differences in fouling were detected between the oyster bags and lantern nets at either site (Appendix 8). Although fouling was appreciably correlated with volume ($r^2 = 0.79$), the collective bulk of attached organisms did not negate the ability to gauge a scallop's shell height by it's volume ($r^2 = 0.80$) (Appendix 10). Fouling organisms, in order of areal predominance on the right valve, were oysters (*Crassostrea virginica*), tube worms (Family Serpulidae) and barnacles (*Balanoides* sp.). The predominant organisms fouling gear were red algae and barnacles in Cheriton; green filamentous and red alga and branching bryozoans on the seaside. Bayside racks were heavily colonized almost exclusively by barnacles, seaside racks harbored occasional tufts of red algae only.

Over-wintering, specifically, from mid-November to mid-February, did not significantly change shell height, non-muscle or muscle masses, or fouling coverage at the bayside site and in seaside oyster bags (Appendices 3-8). Animals in lantern nets on the seaside increased mean shell height and tissue masses between harvests; those in bayside oyster bags increased in volume only, indicating that only the fouling organisms benefitted. Growth rates decreased with declining temperatures, as expected, although it took longer for those in seaside nets to slow down (Appendix 7).

Economic Parameters

Survival of scallops were monitored throughout the study, and are presented by gear type in Figures 10a through 10d. Survival was highest at the bayside for most of the study, although lantern nets, which started out well, performed poorly when compared over a longer term. Bags and trays at Cheriton had similar survival rates at the first harvest (t=98 days post-deployment): 57 and 59%, respectively.

The yield of live bay scallops over a minimum market size of 40 mm was calculated from the survivorship and length data, and is presented by gear type in Figures 11a through 11d. Bayside yields were higher than those on the opposite shore. Trays had the highest percent yield. Oyster bags had higher percent yields than lantern nets on the seaside, and the two gear types eventually had parity on the bayside.

Expenditures, itemized by gear type with notes regarding site differences, are presented in Appendix 11. Maintenance time for seaside units was occupied primarily in scrubbing down the green algae growth, for a total of 81.5 minutes. Fouling on bayside units were very difficult to scrub off due to the intransigence of barnacles, oysters and bryozoans. The primary effort at Cheriton (103.5 minutes total) was spent making repairs caused by barnacles and oysters abrading through lines, mesh and bungee cords. Expenditures for harvests at Cheriton were larger than at Magothy Bay because of the additional time needed to retrieve the units without being lacerated by the fouling. Additional time was also required at the bayside site due to the difficulty of manipulating units that were heavier (from better growth characteristics) in murky water.

Costs were calculated by totaling the mean expenditures for materials and labor ($5.25/hr) to build, deploy and maintain the experimental units. Over their respective lifespans (Table 2), the lantern nets were the most expensive at an average of $114.94 each, the trays and oyster bags were $62.02 and $49.12 each, respectively (Appendix 11).

DISCUSSION

Ambient chl-a needs to be a minimum of about 1.2 μg/L-- less can cause stunting, although more than this does not affect growth (Kirby-Smith and Barber 1974; Rhodes *et al* 1981). The level of chlorophyll-a on the seaside was consistently an order of magnitude less, and could be considered a food-deprived environment from mid-November until the end of the experiment. The scallops at the seaside site probably experienced food limitations for virtually the whole study; the bayside site appeared adequate throughout.

In all likelihood, nutritional want was primarily due to the rapid seaside currents preventing the scallops from feeding as much as they needed to, rather than a short supply of ambient food. (Chlorophyll-a did not become inadequate on the seaside until late in the study.) Work by Kirby-Smith (1972) showed that this species grew best in his slowest experimental current speed of 0.2 cm/sec, while growth came to a virtual halt at a higher speed of 12 cm/sec. Slower currents were postulated as allowing the scallops to open their valves wide enough to feed adequately. Additional evidence for this was the thickened, somewhat shorter seaside valves, which are symptoms of inadequate food levels (Epifanio 1976). Also, if one uses non-muscle mass to infer food availability (as it includes the stomach), it would appear from the overwintering results in the lantern nets that food did not become environmentally unsubstantial until after the second harvest in November, which corresponds to the drop in ambient chlorophyll-a. While ambient food levels were apparently too low after the second harvest, it is not known (though unlikely) if current speeds increased at that time. Any additional increase in water speed in Magothy Bay would reduce even further the access to a faltering food supply. This points at the importance of monitoring of currents when judging site suitability.

Temperature experiments by Kirby-Smith and Barber (1974) indicated that scallops grow faster in warmer water. Bay scallops can tolerate salinities from 14 to 35 ppt (Gutsell, 1932). While salinity optimization studies are lacking, both Mike Castagna (Castagna 1975) and Steve Malinowsky (Foster 1990c) recommend a minimum of about 22 ppt for planting.

Access to food within an enclosure is contingent upon ambient level as well as the ability to feed on it. If one uses non-muscle mass as evidence of feeding success, Tukey's Honest Significant Difference (HSD) tests indicate that the oyster bag and tray were generally more effective than the lantern net. This connection is logical, considering that the net mesh reduced the currents least, thereby allowing the scallops the feed less frequently and/or effectively. Feeding should be able to occur at least during slack tides; not slowing internal water exchange during periods of maximum flow would reduce the proportion of time available for the scallops to feed.

Castagna (1975), working with both floating trays and large pens, suggested that muscle mass is affected by the ability to make "vertical swimming excursions." If that were the case, one would expect to find larger adductors as container depth increased. This study's trays and oyster bags had the same depth of 8.9 cm, while the lantern net tier depth was 20.0 cm; muscle masses decreased with respect to the order listed ($\alpha < 0.05$), thus contradicting the previous assertion. Observations of bay scallops in their enclosures revealed more horizontal 'scooting' than attempts to move vertically. This remained true for the lantern nets, where vertical movement was less impeded by ceilings than in the other gear types. The longest dimensions of the tray, bag and net were 112.4, 87.9 and 50 cm, respectively. Muscle mass decreased in that order as well. Development of the adductor may therefore be more influenced by the ability to move horizontally than in other directions. According to Barber and Blake (1981), adductor muscle size in *Argopecten irradians concentricus* in natural populations is controlled by food availability and reproductive condition. It is possible that the container's shape and porosity could influence food flow more than a scallop's ability to swim. Determination of this effect is especially important if only the adductors are to be marketed for consumption, and may therefore merit further investigation.

Market size for a shell-on product is normally determined by shell height. The criteria for a market size of 40 mm was chosen for this study because that is the smallest that restauranteurs in the southern Virginia area were comfortable with (DuPaul and Oesterling, pers. comm.; DuPaul also states that >45 mm is preferable). The gear that grew the animals to this size the quickest was the tray (Appendix 7). It is possible, however, for slower-growing scallops to do some catching up, as evidenced by the fact that growth rates in seaside nets slowed down after the others did. The mean shell heights for the oyster bag and tray at 98 days (first harvest, bayside) were both over the minimum at 43.0 and 45.1 mm, respectively. At the first harvest, the bayside yields of scallops over 40 mm from the oyster bag, tray and lantern net were 69.8, 82.9 and 59.9%, respectively (Figure 11e); the number of days to 50% over 40 mm for those units was 61.0, 77.8 and 86.0, respectively. The two and a half weeks lag between the tray and the oyster bag may not turn out to be significant to the grower. Certainly the need to harvest earlier would depend on factors such as the immediacy of market demand and seasonal weather patterns.

By late October, the steep increases in yields slowed as the temperature fell and growth levelled out (Figure 12). The oyster bag and lantern net data indicate that the percent yield actually decreases when the animals are held for a longer period of time. (The tray data are too incomplete to include here.) The only exceptions to this pattern were the lantern net from subsite 6 and the oyster bag from subsite

1, and may simply be due to normal variation. Growth in natural populations also appears to slow down as the temperature drops in the Fall (e.g., Belding 1910a; Gutsell 1931; Marshall 1956). Late October/early November is probably a good time to begin the harvest from an August planting.

Use of aggregate volume to estimate time of harvest is possible. The NMFS station routinely employs volumetric measurements to estimate time of harvest (e.g. Rhodes and Widman 1980; Rhodes *et al* 1981; Widman *et al* 1983). The success of this method lies in both the consistency of technique and in the establishment of reference values of volume to shell height. Reference values are probably affected by the size and shape of the container used for measuring, and the level of site-specific fouling at various times of the year. However, this study found that the degree of correlation between shell height and volume is adequate ($r^2=0.80$) to give the operator a good idea as to when to begin assessing shell height for harvest. The usefulness of volumetrics rests on the speed with which measurements may be made. Less time spent out of the water should decrease handling stress (e.g. desiccation and the jarring action that causes a bivalve to shut it's valves) and it's associated consequences (e.g. incompetent tissue function, inability to feed and/or respirate adequately).

Survival rates may have been affected by temperature. The high degree of association (between temperature and survival) using the exploratory method of principle component analysis provides a clear prompt for full experimental study. It is possible that the finding is coincidental, made spurious due to a lack of data regarding the true causal parameters.

The poorer survivorship on the seaside may have been particularly influenced by an inability to feed due to the greater wave energy, in addition to the faster currents and lower ambient food levels. Disturbances cause bay scallops to close their valves, which can reduce respiration and also severely limit their ability to feed (Bruce Barber, pers. comm.). The seaside was a far more (physically) energetic environment, which may have put significant nutritional limitations on the scallops grown there by limiting their opportunities to feed. (There was only one occasion when it was too rough for work at Cheriton, as opposed to 5 or 6 episodes at the seaside site. During those sampling efforts, Magothy Bay's broad expanse of water could rapidly deteriorate into a violent, wave tossed arena by the winds sweeping across it.) If this privation put the animals into a weakened state, they would then be less able to defend themselves from infectious disease. Thus it is possible that persistent physical shock on the seaside may have caused increased mortality.

There is evidence which indicates survivorship was reduced by predation and handling. Blue crabs (*Calinectes sapidus*) and spider crabs (*Labinia emarginata*) were observed on the top or side of every seaside unit at some point during the study, and pieces of broken scallop shells were recovered from underneath the units. On one occasion a spider crab was observed to reach into the second tier of the LN5. It attempted to pull a live scallop through the mesh but only succeeded in crushing the shell. In addition, an oyster toadfish (*Opsanus tau*) was discovered in a burrow beneath the concrete anchor at subsite 6. It is not known whether this animal was able to prey on the scallops directly above. At Cheriton, a pair of blue crabs in mating position were observed twice on oyster bags and a single spider crab was seen once (on the lantern net from subsite 1). The fact that fewer observations of predators were made on the bayside may have been influenced by reduced visibility (normally about 0.5 m as opposed to 1.5-2 m on the seaside).

Handling received during checks for shell height measurements was minimized by keeping the scallops in the water as much as possible and treating them with care on deck. Reports of Chinese culturists blasting the animals off decks with water hoses notwithstanding, bay scallops are considered to be sensitive to motion as well as desiccation (Castagna and Duggan 1971; Duggan 1973; Heffernan *et al* 1988; Foster 1990c), which would act to reduce both survivorship and growth rate. With this in mind, handling was planned and kept constant among all the enclosures. A concurrent study using trays in three tiered racks at the bayside site did not make growth checks, thus receiving no handling, and had mortality rates about 20% lower than the trays in this study (Oesterling 1992, in press).

Further comparisons with other studies are presented in Table 1 (below).

Table 1: Growth rates and mortalities of bay scallops under culture and natural conditions.

Gear Type	Stocking Density (m^{-2})	Initial size (mm)	Final size (mm)	Days	$\bar{x}$ Growth Rate (mm/day)	Mortality (%)	LOCATION	STUDY
Pearl net	555 833	18.1 11.4	48.9 40.7	137 143	0.22 0.20	23 >27	Bluffton, SC	Walker *et al*, 1991a
Lantern net	500 1000	24.0 24.0	46.2 41.7	91 91	0.24 0.19	not reported	Milford, CT	Rhodes & Widman, 1980
Trays	833	14.4	40.5	128	0.20	16.0	Wachapreague, VA	Duggan, 1973
Lantern net	555	17.8	33.5	78	0.20	0.0	Milford, CT	Widman & Rhodes, 1991
Natural environment	n/a	20 to 24	45 to 49	89	0.24 to 0.32	44.2	Pivers Island, SC	Gutsell, 1930
Natural environment	n/a	26.1	51.7	169	0.15	not reported	Alligator Harbor, FL	Sastry, 1961
Natural environment	n/a	20	50	119	.22	not reported	Anclote Estuary, FL (*A. i. concentricus*)	Barber & Blake, 1983
Natural environment	42	19.2	38.5	93	0.21	97	Waterford, CT	Morgan *et al*, 1980
Pearl net	753	9.8	43.2	203	0.16	53.0	Wassaw Sound, GA	Heffernan *et al*, 1988
Oyster bag	700	24.0	42.9	98	0.19	43.1	Cheriton, VA	Present
Tray	700	24.0	45.1	98	0.22	37.0	Cheriton, VA	Present
Lantern net	700	24.0	40.9	98	0.17	45.1	Cheriton, VA	Present
Oyster bag	700	24.0	39.6	97	0.16	55.0	Magothy Bay, VA	Present
Lantern net	700	24.0	33.4	97	0.10	54.9	Magothy Bay, VA	Present

The high degree of mortality in this study was largely unavoidable due to the research constraint of needing to check growth. Bay scallop farmers could avoid this by not disturbing their enclosures until close to harvest time. In addition, growth rates could be enhanced by deploying earlier than what was possible in this study. Conditioning of brood stock could start in February, allowing deployment to be as early as June. This would put the animals into the field as the water temperature is rising, instead of at the declining portion of the seasonal temperature curve. An earlier deployment could also enhance survivorship by giving the scallops more time to grow, thus increasing robustness.

Work by Duggan (1973), and Walker *et al* (1991a) and Heffernan *et al* (1991) suggest that mortality is proportional to stocking density, while inversely proportional to the rate of growth. Because no other studies have specifically stocked bay scallops at 700 m^{-2}, reported values of mortality and growth rates (given in Table 1) are not directly comparable. They do, however, provide a relative framework within which this study may be viewed.

There is a wide range of mortality estimates in the available literature (e.g., Widman and Rhodes 1991; Walker *et al* 1991b; Heffernan *et al* 1988) and an apparent tendency towards higher mortalities in studies that disturbed the scallops more (e.g., Foster 1990c; Heffernan *et al* 1988; Castagna and Duggan 1971; Castagna 1975) (Table 1). Mortality of enclosure-reared scallops is also affected by excessive siltation (Castagna 1975), although the smothering that this can cause did not appear to be a problem in this study. Survivorship of hatchery-reared *Argopecten irradians* animals stocked in Connecticut *Zostera marina* beds was extremely low (~3%), apparently due to heavy predation (Morgan *et al* 1980). (This underscores the need for measures to exclude predators, such as enclosures, if an aquaculture venture is to be successful.) The sources of mortalities identified in this study (disturbance and predation) are aspects which are central to the determination of gear suitability for commercial applications.

While mortality in this study was high when harvested at 98 days, it was higher still in subsequent harvests. Over-wintering in the field proved to be of very limited benefit to the scallops and resulted in heavy gear loss. It is therefore not recommended for further examination, nor for commercial processes where avoidable. It could possibly be avoided by deploying earlier, thereby taking advantage of higher water temperatures to enhance growth (Oesterling 1992, in press; Barber pers. comm.).

Growth rates for the bayside units were within the range of other culture studies, although lantern nets were on the lower end of the spectrum (Table 1). Growth rates in seaside units were markedly lower than most other aquaculture efforts for this species. All units except seaside lantern nets fell within the range of growth under natural conditions, i.e., without enclosures, as reported by Sastry (1961) and Morgan *et al* (1980). While the latter was a re-stocking study using hatchery-reared animals, it did not indicate if the growth rate was influenced by size selection of previous generations. Even so, the growth rate reported by Morgan *et al* (1980) was somewhat lower than that found in Gutsell (1930). Gutsell's (1930) account of shell height in a natural population was given by size classes; the high end of the range is less likely to be observed, as it is well above all other reported values. Growth rates found in this study are therefore not unusually low, with the exception of seaside lantern nets.

It is not clear from the available literature whether placing *Argopecten irradians* into enclosures reduces shell growth. If growth is slowed down, however, it is probably not by much, and far outweighs the disadvantages of predation (note Morgan *et al* 1980). Given the information on current speed provided by Kirby-Smith and Barber (1974), it would make sense to deploy enclosures whose architecture reduces currents around the scallops in locales where it is otherwise high. It is axiomatic that where lower current speeds are the norm, a more open structure would be advisable to allow better access to food. Thus one would perhaps consider trays with solid walls in areas such as the seaside of the Eastern Shore, and either trays or smaller-meshed oyster bags (e.g. 12 mm) on the bayside. The lantern nets are clearly inappropriate in either location and may be best suited for deep water or pond culture (e.g. Widman and Rhodes 1991 and Walker *et al* 1991).

Epibenthic fouling of scallop shells is not a major factor in consumer acceptance in southern Virginia restaurants (DuPaul and Oesterling pers. comm.). For the whole-animal market, only relatively minor work is needed to scrub off most of the tube worms still in their early, sand covered stage (as this can have a deleterious effect on sauces prepared from poaching liquids). According to DuPaul and Oesterling, restaurant patrons frequently consider the remaining oysters as bonus tidbits. Fouling of *Argopecten irradians irradians* is not likely to affect the shucked product either, although this depends in what method is to be used (machine or hand) and remains to be explored more fully. The sale of whole bay scallops in a seafood market might be adversely affected by heavily fouled shells, especially when compared to the clean shells of, for example, *Mercenaria mercenaria*. The fouling not only diminishes the aesthetic appeal of the bay scallops, it tends to accumulate small quantities of mud as well as harbor organisms that cannot be effectively scrubbed off, e.g., wire-like bryozoans. Even if the scallop itself is in fine shape, a consumer could be turned away by the odors when the mud becomes anaerobic or when the fouling organisms begin to decompose. It is for these reasons that bay scallops with the degree of fouling found on the animals in this study will probably fare best in a restaurant-oriented marketplace.

Oyster fouling could potentially be a problem to growth, as both host and epiphyte are filter feeders. Several instances were observed where 3-5 oysters, starting from the scallop's hinge area, grew over the opposite end. It is quite possible that the oysters would compete with scallops for food. Because the correlation between shell height and shell fouling is ambiguous ($r^2=0.575$), more research is needed on this question.

It would be interesting to measure the chlorophyll-a (chl-a) concentration inside fouled enclosures and compare it to the ambient level. If chl-a was adequate outside yet reduced within the structure to below 1.2 μg/L, it would benefit the grower to either remove the fouling organisms or to put the scallops into a fresh one. It would be of greater significance still, but prohibitively difficult, if the ambient chl-a concentration was compared to that within a scallop's cavity. That way, one could examine the effect of shell fouling as well. A comparison of external vs. internal enclosure chl-a levels is recommended for growers whose scallops experience severe fouling.

If the survivorship in this study was adversely affected by handling, it is possible to estimate expected values based on data *sans* handling (Oesterling 1992, in press). By finding the ratio of survivorship between the trays of similar stocking density in that study and the experimental units here, handling associated mortality was factored out. (Losses caused by predation are presumably unaffected constants.) The handling-adjusted survivorship data was then applied to each unit's yield and averaged by gear type and site, which is presented in

Figure 13. The late October/early November drop in production rate is more pronounced than in the unadjusted data, and more clearly delineates the optimal time to begin harvests. Further calculations show that the cost per bay scallop produced (gear cost/yield) would be lowest for bayside bags, followed by bayside trays, seaside oyster bags, bayside lantern nets and seaside lantern nets. Again, the gear costs are only relative and preliminary, developed to facilitate comparisons between gear and sites. Calculations needed by commercial growers would include such items as allowances for site access (e.g., fuel, boat, leases, etc.), transport to buyer (truck, containers, ice, fuel, etc.), seed production or purchase and factors associated with marketing. Financial deficits incurred when gear was lost were also not included.

Based on the performances in this study, one could expect gear to be fairly dependable in accordance with the following table:

Table 2: Physical performance expectations of the major gear employed.

Gear	Expected life span (years)	Probable point(s) of failure
FRP rack	6 to 8	at bolt holes
concrete anchor	indefinite	none
lantern net	0.75 to 1.5	mesh (strength inadequate)
tray	6 to 8	attachment devices; clips for top mesh; also plastic becomes brittle, causing corners and edges to break
oyster bag	6 to 8	mesh eventually becomes brittle

The (partially estimated) unit cost of production for bayside oyster bags ($0.112) should be compared to the market value. At this time (Spring, 1992), the only bay scallop mariculture operation that is taking the animals to a marketable size on a commercial scale is Taylor Industries, in Massachusetts. Their May, 1992 retail price for whole, cultured scallops was $0.25 per 45-50 mm animal, which is up one cent from last year (Rodman Taylor, pers. comm.). A more complete pilot-scale study is now required for the lower Eastern Shore to evaluate true economic feasibility. Initially it will be easiest for people who already have a mariculture niche to incorporate this species into their operations. Cherrystone Aquafarms, for example, can readily adapt their *Mercenaria mercenaria* facilities for bay scallop culture, with very little modification needed. Individuals who have been growing oysters on a small scale would also already be familiar with aquaculture techniques and therefore have a good potential for success. Difficulties with permitting the use of the water column for aquaculture in Virginia need to be solved in order to make this crop feasible on a broad scale. The fast growth and relatively high price could make bay scallops a viable substitute for the failed Chesapeake Bay oyster industry.

CONCLUSIONS

Considerations for the selection of an appropriate site for the mariculture of *Argopecten irradians irradians* should include measurements of current speeds and chlorophyll-a, as well as a general knowledge of temperature regime and vulnerability to storms. The bayside site at Cheriton, Virginia, proved to be a better location for bay scallop culture than on the opposite shore in Magothy Bay. Reasons for this include adequate food levels during the study period at Cheriton and currents slow enough to allow access to that food, and slightly warmer water, which enhances growth rates. In addition, the site in Magothy Bay was vulnerable to strong currents which swept gear away.

The polyethylene oyster bag with 15 mm square mesh was the best of the three gear types tested. Although the trays produced marketable scallops about two weeks sooner, oyster bags had the lowest expected unit costs primarily due to a lower capital outlay. The oyster bag also proved functionally superior because they were very easy for one person to deploy and retrieve regardless of working conditions, due to a very manageable size. In addition, their shape and mesh structure make them highly adaptable to various deployment schemes (e.g. different rack types), yet the material proved durable. Finally, they are readily available and none were lost in spite of some severe storms. A non-disposable method of closing the ends, such as attaching surgical tubing might be a worthwhile improvement that would reduce both costs and the potential release of plastic cable-tie waste into the environment. Racks could be made of welded "re-bar" (construction rod) stock at a much lower cost than FRP, although life span would probably be somewhat reduced.

The trays were the second-best choice for grow-out enclosures, based on the growth parameters measured. The polyethylene trays used in this study are not available for public purchase. They were formed from a mold owned by the operators of Cherrystone Aquafarms, Mr. Chad Ballard, and subsequently loaned by him for this research. It is possible to make trays like those used here out of materials readily available from the hardware store, or to adapt other structures, such as plastic chicken-transport boxes, by lining them with appropriately sized polyethylene mesh. Five of the six deployed trays were lost prior to harvest. This should be preventable. A more secure way of holding the tray to the rack top needs to be developed- a rigid, pivotable bar, e.g. made of FRP, clamped over the top would probably suffice. Future trays should be constructed with the number of people handling them and water depth in mind. It was found to be virtually impossible for one person to maneuver these large, cumbersome enclosures in water higher than about one and a half meters. Even with two people handling them, the trays could still be built smaller to reduce the amount of time required for manipulation.

The lantern nets' advantages were the relative simplicity of deployment, harvest and maneuverability, facilitated by the simple act of un/clipping to a ring and the velcro seams. Yet the lantern nets were the least likely choice both economically and functionally for several reasons. The delay in the development of the scallops grown in lantern nets proved to be a critically limiting factor where commercially adequate yields are concerned. The ease with which the mesh was inadvertently ripped during operations and cut by the sharp edges of fouling oysters was alarming. Also, the large mesh made the lantern nets the gear most vulnerable to predation. Because lantern nets are suspended in the water column by a floating buoy, the bottom tier often rests on the substrate at low tide. Low oxygen conditions or relatively high concentrations of particulate matter there may reduce survival and/or growth rates, making lantern nets deployed in this manner inappropriate to the shallow waters of the Eastern Shore. While there appears to be only one general type of lantern net in production, it may be possible to re-visit this gear if manufacturers could be convinced to make some samples with smaller, stronger mesh.

Were this study to be repeated, a greater effort to more closely monitor current speeds would be made. An increase in replicates to include enclosures that were not disturbed during the grow-out process would also be warranted. Finally, an comparison of ambient chlorophyll-a and that found inside enclosures would be made to gauge the severity of the effects of gear fouling.

This research shows that the gear types and sites examined bear distinct biological and economic differences in bay scallops. Selection of the two factors requires careful consideration for a successful mariculture operation. While some small technical details remain to be worked out, gear and site performance levels showed an excellent degree of biological feasibility for the final grow-out of *Argopecten irradians irradians* on the lower Eastern Shore. The economic data presented here indicate that a financially productive mariculture operation may be possible, particularly if combined with other crops, such as hard shell clams. Pilot studies to determine and disseminate technical, economic and logistical are underway and should provide growers with critical information.

APPENDICES

APPENDIX 1

Schedule of variable measurement dates[1].

	Shell height	Shell volume	Salinity	Temper-ature	Chloro-phyll-a	Current speed	Tissue[2] masses	Shell fouling
13/14AUG91 (deployment)	*	*	*	*	*			
03/04SEP91	*	*	*	*				
17/18SEP91	*	*	*	*				
24/25SEP91	*	*	*	*	*			
01/05OCT91	*	*	*	*		*		
25/26OCT91	*	*	*	*				
12/13NOV91			*	*	*			
18NOV91 (harvest)	*	*	*	*		*	*	*
11DEC91 (harvest)	*	*	*	*		*	*	*
13FEB92 (harvest)	*	*	*	*		*	*	*

1: Dates are for successfully completed attempts only.
2: Wet weights were of a) combined adductor/abductor and b) combined other non-muscle tissues.

APPENDIX 2

Results and Discussion of differences between lantern net tiers.

Determination of differences between tiers in a lantern net was done by multiple analysis of variance at the $\alpha = 0.05$ level of significance. Nets found to be different were tested further by Tukey's HSD (Honest Significant Difference) method, again using the $\alpha = 0.05$ level of significance. There were very few clear, consistent trends among the data analyzed. Recall also that there was no evidence to reject the null hypothesis of no pseudo-replication between subsites, which allows overwintering comparisons to be made.

Lantern nets from subsites 4 and 6, both seaside, showed no differences between tiers among any of the variables. Given that no one tier showed any consistent difference between any other, it may be that the significance that did show was merely due to natural random variations. Since 135 paired comparisons within nets were made, at $\alpha = 0.05$, one would expect, on average, to bear 6 or 7 anomalies due to random variation. As there were 17 found, something more could be expected to be going on. The most likely source, due to it's frequency, was the top tier ("c") from subsite 2 (LN2). Scallops grown there were smaller, grew slower and had lower non-muscle and muscle masses (n=8 findings). The reason for this is unfathomable, as it was treated no differently from the other tiers or nets. Further experimentation is needed to determine if this result can be repeated, and what the causes were.

Overwintering had a depth-related effect on the bayside. As the tide ebbs, the buoy suspending the net drops, sometimes allowing the bottom tier ("f") to come in contact with the substrate. Wave motion pushed the nets back and forth, and was sometimes observed to cause tier "f" to create a layer of re-suspended sediment several centimeters thick. Bay scallops are known to have difficulties functioning when particulate matter becomes too concentrated (Stone and Palmer 1975), possibly because suspended sediments tend to increase biological and chemical oxygen demands (BOD and COD, respectively) in the water column. The effect of an increase in BOD and COD on the scallops in lantern net tiers should increase with depth. It appears, though, that if given enough time on the bayside, the bottom tier can 'catch up' to the others. The reason this was not found to the same degree on the seaside might be due to the fact that a) less material was present to be re-suspended, b) what lay underneath the organic matter was clay-like and thus less able to stay in suspension, and c) the strong currents would flush the suspension away quicker than on the bayside. Further investigation involving dissolved oxygen and particulate matter monitoring at precise tier depths needs to be done, as well as visual monitoring of the suspensions over tidal cycles.

At the first harvest, all the scallops' variables from each bayside tier had values larger than those from corresponding seaside tiers. This concurs with data from the oyster bags, and is likely due primarily to the current speed and food regimes at the sites (see Discussion). The anomalous yet consistent finding for the top tier in the second harvest indicates that while a larger trend exists, exceptions can and do occur. No clear reason for this phenomenon is evident, and only one possible explanation comes to mind. That is the normal, random variation that would be expected from doing this many comparisons. Examining 35 contrasts at $\alpha = 0.05$, one might anticipate one or two unexpected findings. Of the four tiers, "c" would be most likely to show similarities, because it occupied the potentially most homogenous and least disturbed position. This still does not explain why no gradient appeared with lower tiers, or why this was not observed at the first harvest. Had the lantern net from subsite 1 survived to the third harvest, more clues might be offered to answer these questions, such as whether this represents the seaside units starting to 'catch up' to the bayside units. Further experiments might look for significant trends by deploying a large number of lantern nets at both sites, and harvesting every two or three weeks.

Epibenthic fouling of scallop shells was not different between the tiers of any net at any time. It is possible that the criteria for judging the level of fouling was not sensitive enough to discover significant differences (i.e., 0-33%, 34-66% and 67-100% coverage on the right valve). An alternative to visual inspection would employ a photocopy machine to photograph the valve, and then to use the digitizer to trace the area of fouling vs. the area of the shell. Differences in shell curvatures could be accommodated if necessary by creating size classes. That the animals grown in the bayside tiers were consistently more fouled than their seaside site counterparts is in agreement with the general findings for the oyster bags. It is probably because there is more food in the bayside waters, with correspondingly greater quantities of fouling organisms. The slower current there might allow more opportunity for attachment as well.

APPENDIX 3: Multiple analysis of variance and covariance p-values.

Variable	Between sites	Between gear, within site: Bayside	Seaside
Shell height	≤ 0.00	≤ 0.00	≤ 0.00
Growth rate	≤ 0.00	≤ 0.00	≤ 0.00
Muscle mass	≤ 0.00	≤ 0.00	≤ 0.00
Non-muscle tissue mass	≤ 0.00	≤ 0.00	≤ 0.00
Fouling coverage	≤ 0.00	0.02	0.74
Volume	≤ 0.00	≤ 0.00	≤ 0.00

APPENDIX 4: Results of Tukey's HSD comparisons of bay scallop shell heights at $\alpha = 0.05$.

HARVEST #1	HARVEST #2	HARVEST #3	SITES	OVER-WINTERING	UNIT MEANS (mm)		
B3 < T3	B2 = L2	B1 > L4	B1 > B4	L2 = L3	B1=44.12	L2=41.96	T3=45.10
B3 > L3	B2 > L5	B4 > L4	B2 > B5	B1 = B2 = B3	B2=42.24	L3=40.87	
B3 > L6	B5 > L2		B3 > B6	B4 = B5 = B6	B3=42.95	L4=35.06	
B6 < T3	B5 > L5		L2 > L5	L4 = L5 > L6	B4=38.95	L5=36.01	
B6 = L3			L3 > L6		B5=38.98	L6=33.35	
B6 > L6					B6=39.62		
T3 > L3							
T3 > L6							

B = Oyster bag
L = Lantern net
T = Tray

Enclosures from subsites 1, 2 and 3 were on the bayside of the Eastern Shore (Cheriton, VA).
Enclosures from subsites 4, 5 and 6 were on the seaside of the Eastern Shore (Magothy Bay, VA).

Units B3, L3, T3, B6 and L6 were harvested first, on 18 November, 1991.
The second harvest, of units B2, L2, B5 and L5, was made on 11 December, 1991.
Units B1, B4 and L4 were harvested last, on 14 February, 1992.
Enclosures T1, T2, T4, T5, T6 and L1 were lost prior to harvest.

Sample sizes were $n \geq 50$.

APPENDIX 5: Results of Tukey's HSD comparisons of bay scallop non-muscle tissue masses at $\alpha = 0.05$.

HARVEST #1	HARVEST #2	HARVEST #3	SITES	OVER-WINTERING	UNIT MEANS (g)		
B3 = T3	B2 = L2	B1 > L4	B1 = B4	L2 = L3	B1=7.31	L2=5.61	T3=7.05
B3 = L3	B2 > L5	B4 = L4	B2 > B5	B1 = B2 = B3	B2=6.28	L3=5.62	
B3 > L6	B5 < L2		B3 > B6	B4 = B5 = B6	B3=6.27	L4=3.12	
B6 < T3	B5 = L5		L2 > L5	L4 = L5 > L6	B4=3.83	L5=2.75	
B6 > L3			L3 > L6		B5=3.34	L6=2.05	
B6 > L6					B6=3.08		
T3 > L3							
T3 > L6							

B = Oyster bag
L = Lantern net
T = Tray

Enclosures from subsites 1, 2 and 3 were on the bayside of the Eastern Shore (Cheriton, VA).
Enclosures from subsites 4, 5 and 6 were on the seaside of the Eastern Shore (Magothy Bay, VA).

Units B3, L3, T3, B6 and L6 were harvested first, on 18 November, 1991.
The second harvest, of units B2, L2, B5 and L5, was made on 11 December, 1991.
Units B1, B4 and L4 were harvested last, on 14 February, 1992.
Enclosures T1, T2, T4, T5, T6 and L1 were lost prior to harvest.

Sample sizes were $n \geq 50$.

APPENDIX 6: Results of Tukey's HSD comparisons of bay scallop muscle tissue masses at $\alpha = 0.05$.

HARVEST #1	HARVEST #2	HARVEST #3	SITES	OVER-WINTERING	UNIT MEANS (g)		
B3 < T3	B2 = L2	B1 > L4	B1 > B4	L2 = L3	B1=3.38	L2=2.78	T3=3.80
B3 = L3	B2 > L5	B4 = L4	B2 > B5	B1 = B2 = B3	B2=2.94	L3=2.96	
B3 > L6	B5 < L2		B3 > B6	B4 = B5 = B6	B3=3.15	L4=1.15	
B6 < T3	B5 = L5		L2 > L5	L4 > L5 = L6	B4=1.32	L5=1.01	
B6 > L3			L3 > L6		B5=1.30	L6=0.68	
B6 = L6					B6=1.12		
T3 > L3							
T3 > L6							

B = Oyster bag
L = Lantern net
T = Tray

Enclosures from subsites 1, 2 and 3 were on the bayside of the Eastern Shore (Cheriton, VA).
Enclosures from subsites 4, 5 and 6 were on the seaside of the Eastern Shore (Magothy Bay, VA).

Units B3, L3, T3, B6 and L6 were harvested first, on 18 November, 1991.
The second harvest, of units B2, L2, B5 and L5, was made on 11 December, 1991.
Units B1, B4 and L4 were harvested last, on 14 February, 1992.
Enclosures T1, T2, T4, T5, T6 and L1 were lost prior to harvest.
Muscle mass includes adductor and abductor.
Sample sizes were $n \geq 50$.

APPENDIX 7: Results of Tukey's HSD comparisons of bay scallop growth rates at $\alpha = 0.05$.

HARVEST #1	HARVEST #2	HARVEST #3	SITES	OVER-WINTERING	UNIT MEANS (mm/day)		
B3 < T3	B2 = L2	B1 > L4	B1 > B4	L2 < L3	B1=0.11	L2=0.14	T3=0.21
B3 > L3	B2 > L5	B4 > L4	B2 > B5	B1 < B2 < B3	B2=0.15	L3=0.17	
B3 > L6	B5 = L2		B3 > B6	B4 < B5 < B6	B3=0.19	L4=0.06	
B6 < T3	B5 > L5		L2 > L5	L4 < L5 = L6	B4=0.08	L5=0.10	
B6 = L3			L3 > L6		B5=0.13	L6=0.10	
B6 > L6					B6=0.17		
T3 > L3							
T3 > L6							

B = Oyster bag
L = Lantern net
T = Tray

Enclosures from subsites 1, 2 and 3 were on the bayside of the Eastern Shore (Cheriton, VA).
Enclosures from subsites 4, 5 and 6 were on the seaside of the Eastern Shore (Magothy Bay, VA).

Units B3, L3, T3, B6 and L6 were harvested first, on 18 November, 1991.
The second harvest, of units B2, L2, B5 and L5, was made on 11 December, 1991.
Units B1, B4 and L4 were harvested last, on 14 February, 1992.
Enclosures T1, T2, T4, T5, T6 and L1 were lost prior to harvest.

Sample sizes were $n \geq 50$.

APPENDIX 8: Results of Tukey's HSD comparisons of bay scallop epifouling at $\alpha = 0.05$.

HARVEST #1	HARVEST #2	HARVEST #3	SITES	OVER-WINTERING	UNIT MEANS*		
B3 = T3	B2 = L2	B1 > L4	B1 > B4	L2 = L3	B1=2.0	L2=1.8	T3=1.6
B3 = L3	B2 > L5	B4 = L4	B2 > B5	B1 = B2 = B3	B2=2.0	L3=2.0	
B3 > L6	B5 < L2		B3 > B6	B4 = B5 = B6	B3=1.9	L4=1.1	
B6 < T3	B5 = L5		L2 > L5	L4 = L5 = L6	B4=1.1	L5=1.3	
B6 < L3			L3 > L6		B5=1.4	L6=1.1	
B6 = L6					B6=1.0		
T3 < L3							
T3 > L6							

B = Oyster bag
L = Lantern net
T = Tray
Enclosures from subsites 1, 2 and 3 were on the bayside of the Eastern Shore (Cheriton, VA).
Enclosures from subsites 4, 5 and 6 were on the seaside of the Eastern Shore (Magothy Bay, VA).
Units B3, L3, T3, B6 and L6 were harvested first, on 18 November, 1991.
The second harvest, of units B2, L2, B5 and L5, was made on 11 December, 1991.
Units B1, B4 and L4 were harvested last, on 14 February, 1992.
Enclosures T1, T2, T4, T5, T6 and L1 were lost prior to harvest.
Sample sizes were $n \geq 50$.

*Fouling on right valve only was estimated by visual inspection as low (= 0-33%), medium (34-67%) or high (68-100%), and assigned values of 1, 2 or three, respectively.

APPENDIX 9: Results of Tukey's HSD comparisons of bay scallop volumes at $\alpha = 0.05$.

HARVEST #1	HARVEST #2	HARVEST #3	SITES	OVER-WINTERING	UNIT MEANS (ml/scallop)		
B3 = T3	B2 = L2	B1 > L4	B1 > B4	L2 = L3	B1=70.5	L2=45.3	T3=48.1
B3 = L3	B2 > L5	B4 = L4	B2 > B5	B1 > B2 > B3	B2=61.3	L3=46.0	
B3 = L6	B5 < L2		B3 > B6	B4 = B5 = B6	B3=47.2	L4=21.3	
B6 < T3	B5 = L5		L2 > L5	L4 = L5 = L6	B4=27.5	L5=19.0	
B6 < L3			L3 > L6		B5=28.4	L6=15.8	
B6 = L6					B6=25.5		
T3 > L3							
T3 > L6							

B = Oyster bag
L = Lantern net
T = Tray

Enclosures from subsites 1, 2 and 3 were on the bayside of the Eastern Shore (Cheriton, VA).
Enclosures from subsites 4, 5 and 6 were on the seaside of the Eastern Shore (Magothy Bay, VA).

Units B3, L3, T3, B6 and L6 were harvested first, on 18 November, 1991.
The second harvest, of units B2, L2, B5 and L5, was made on 11 December, 1991.
Units B1, B4 and L4 were harvested last, on 14 February, 1992.
Enclosures T1, T2, T4, T5, T6 and L1 were lost prior to harvest.

Sample sizes were $n \geq 50$.

APPENDIX 10: Values of r^2 from linear regressions of variable means.

	MUSCLE MASS	NON-MUSCLE MASS	FOULING	VOLUME	GROWTH RATE
SHELL HEIGHT	0.800	0.857	0.575	0.802	0.514
MUSCLE MASS	---	0.969	0.746	0.812	0.475
NON-MUSCLE MASS	---	---	0.732	0.900	0.573
FOULING	---	---	---	0.790	0.182
VOLUME	---	---	---	---	0.454

APPENDIX 11: Expenditures for materials and labor.

	MATERIALS (1991 dollars)			LABOR (average time x $5.25/hr)						
				ASSEMBLY			DEPLOYMENT	HARVEST	MAINTENANCE	
ITEM	BAG	TRAY	LANTERN NET	BAG	TRAY	LANTERN NET			Repairs	Cleaning
oyster bag	4.97	0.00	0.00	3.94	0.00	0.00	0.88	0.44	0.00	3.49
tray	0.00	18.72	0.00	0.00	0.88	0.00	2.63	1.93	0.98	0.35
lantern net	0.00	0.00	39.50	0.00	0.00	6.30	0.18	0.88	1.60	1.25
rack: FRP+bolts	53.46	73.61	0.00	7.35	8.66	0.00	1.23		0.13	0.00
anchor: concrete+form	0.00	0.00	6.82	0.00	0.00	2.63	0.26		0.00	0.00
bungee cord	0.60	1.50	0.00	1.31	1.93	0.00				
snap hooks & U-bolts	0.00	0.00	15.49	0.00	0.00	0.00				
3/8" cordage	0.00	0.00	0.75	0.00	0.00	2.63				
1/4" cordage	0.75	0.75	0.75	0.00	0.00	0.00				
buoys	1.62	1.62	9.99	0.44	0.44	2.28				
adhesive	0.50	0.50	0.00	1.31	1.31	0.00				
TOTAL	61.90	96.70	73.30	14.35	13.21	13.83				
Expected life span (years) (See Table 2)	8	8	.75							
TOTAL COST/yr FOR BAG	49.12									
TOTAL COST/yr FOR TRAY		62.02								
TOTAL COST/yr FOR LANTERN NET			114.94							

Deployment times for racks did not differ by site.

Maintenance times were 81.5 minutes for seaside units (primarily scrubbing), and 103.5 minutes for enclosures on the bayside (primarily repairs).

Maintenance costs for trays is adjusted by time and the number extant.

Harvest of bayside units took an average of 50% longer than those on the seaside.

APPENDIX 12: Harvest dates with notes identifying lost gear.

SUBSITE #	BAYSIDE (CHERITON)	LOST	HARVEST DATE	LOST	SUBSITE #	SEASIDE (MAGOTHY BAY)
1	oyster bag		13 February, 1992		4	oyster bag
1	tray	*		*	4	tray
1	lantern net	*			4	lantern net
2	oyster bag		11 December, 1991		5	oyster bag
2	tray	*		*	5	tray
2	lantern net				5	lantern net
3	oyster bag		18 November, 1991		6	oyster bag
3	tray			*	6	tray
3	lantern net				6	lantern net

* indicates unit was lost prior to harvest

APPENDIX 13

Figures 1 through 15

FIGURE 1: An oyster bag. Polyethylene bag had 15 mm square mesh, and were held to the top of a rack via the bungee cords woven through the bottom.

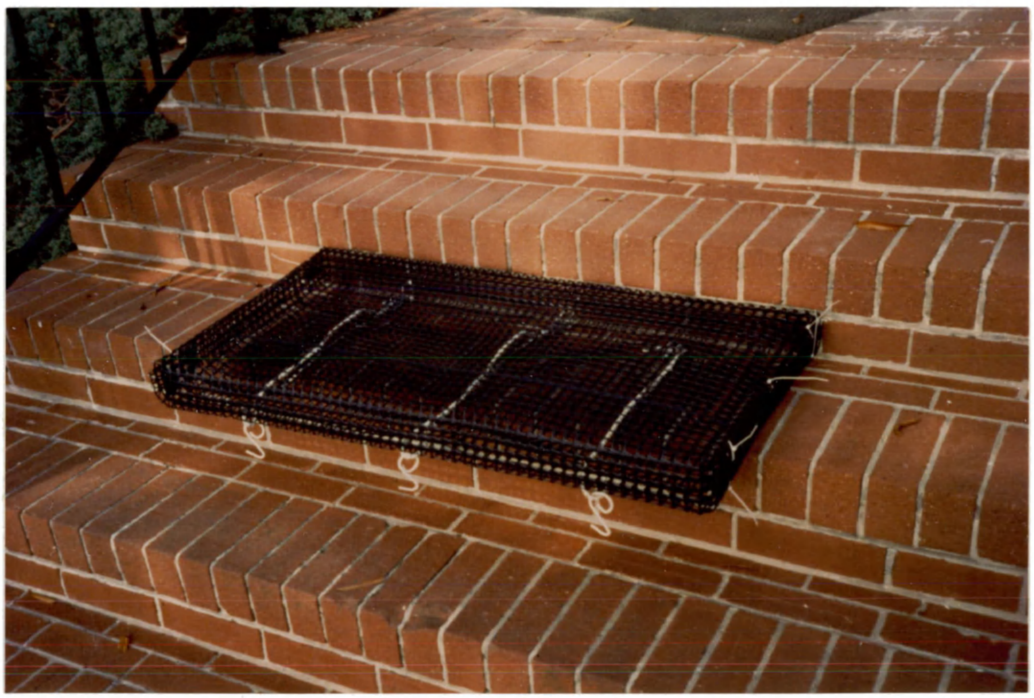


FIGURE 2: A tray. The polyethylene trays had solid sides, 4 mm mesh on the bottom and 12 mm mesh across the top. They were held to rack tops by bungee cords.

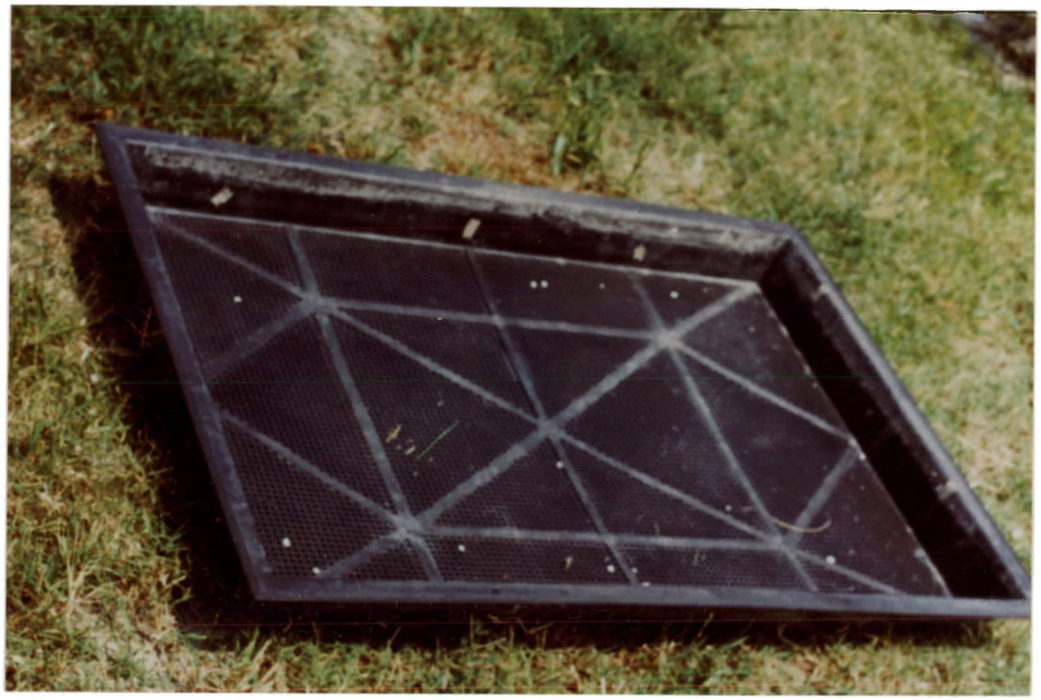


FIGURE 3: A four-tiered lantern net. 14 mm lantern net mesh was made of polyethylene, with aluminum tier hoops and nylon suspension ropes. Each lantern net was suspended between a 36 kg anchor and crab pot buoys using stainless steel carbines.

FIGURE 4: Map of lower Chesapeake Bay showing the two research sites on the Eastern Shore: Cheriton, VA (bayside) and Magothy Bay (seaside).

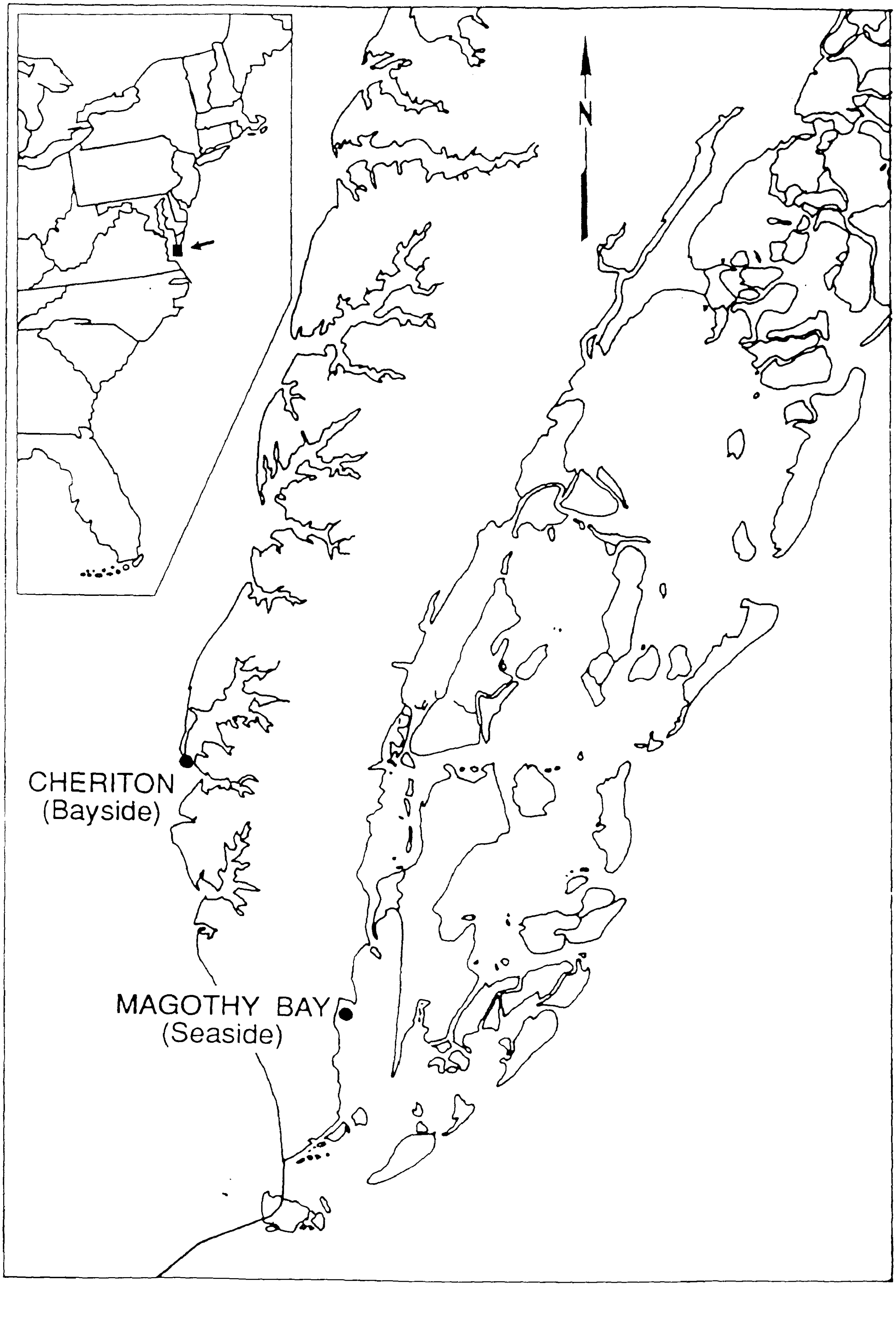

N
CHERITON
(Bayside)
MAGOTHY BAY
(Seaside)

FIGURE 5: Measuring board used for recording shell height. A scallop is butted hinge-first onto the vertical piece, and a needle hole is punched into the paper at the bill end. The distance between the left edge of the paper and each perforation was then measured using a Numonics digitizer and fed directly into a Minitab data file.

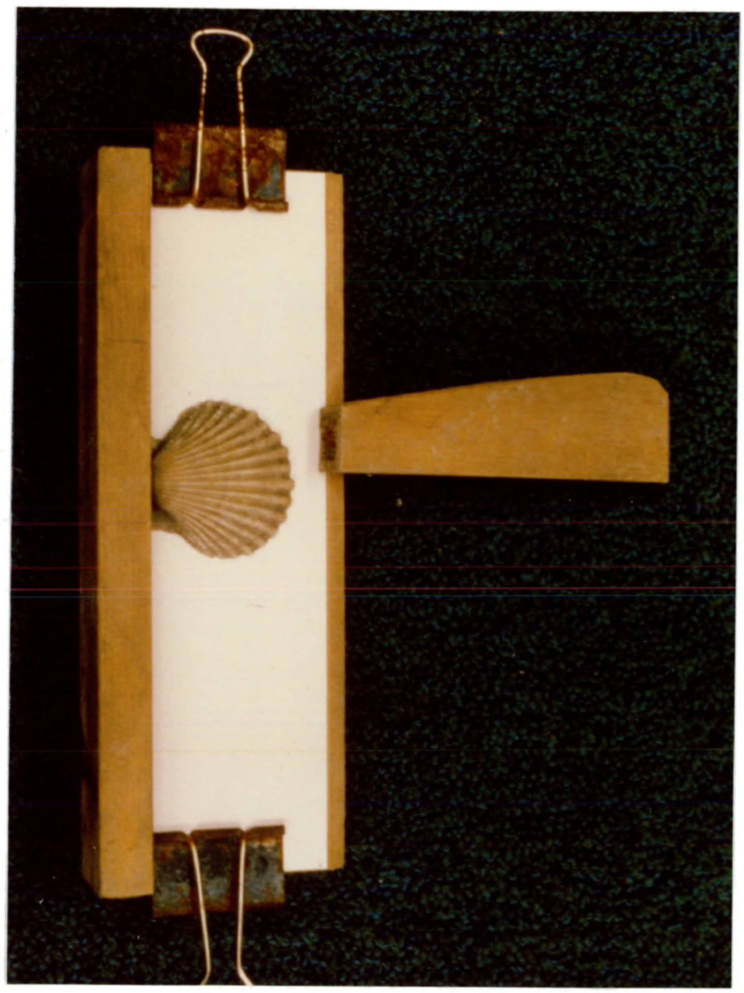


FIGURE 6: Graph of chlorophyll-a abundance at Cheriton and Magothy Bay, VA, research sites during the period prior to the first harvest. Chlorophyll-a abundance is an indicator of food availability for bay scallops; levels above *ca.* 1.2 μg/l allow maximal growth for *Argopecten irradians* (Kirby-Smith and Barber 1974).

* indicates time of high tide at Wachapreague, VA.

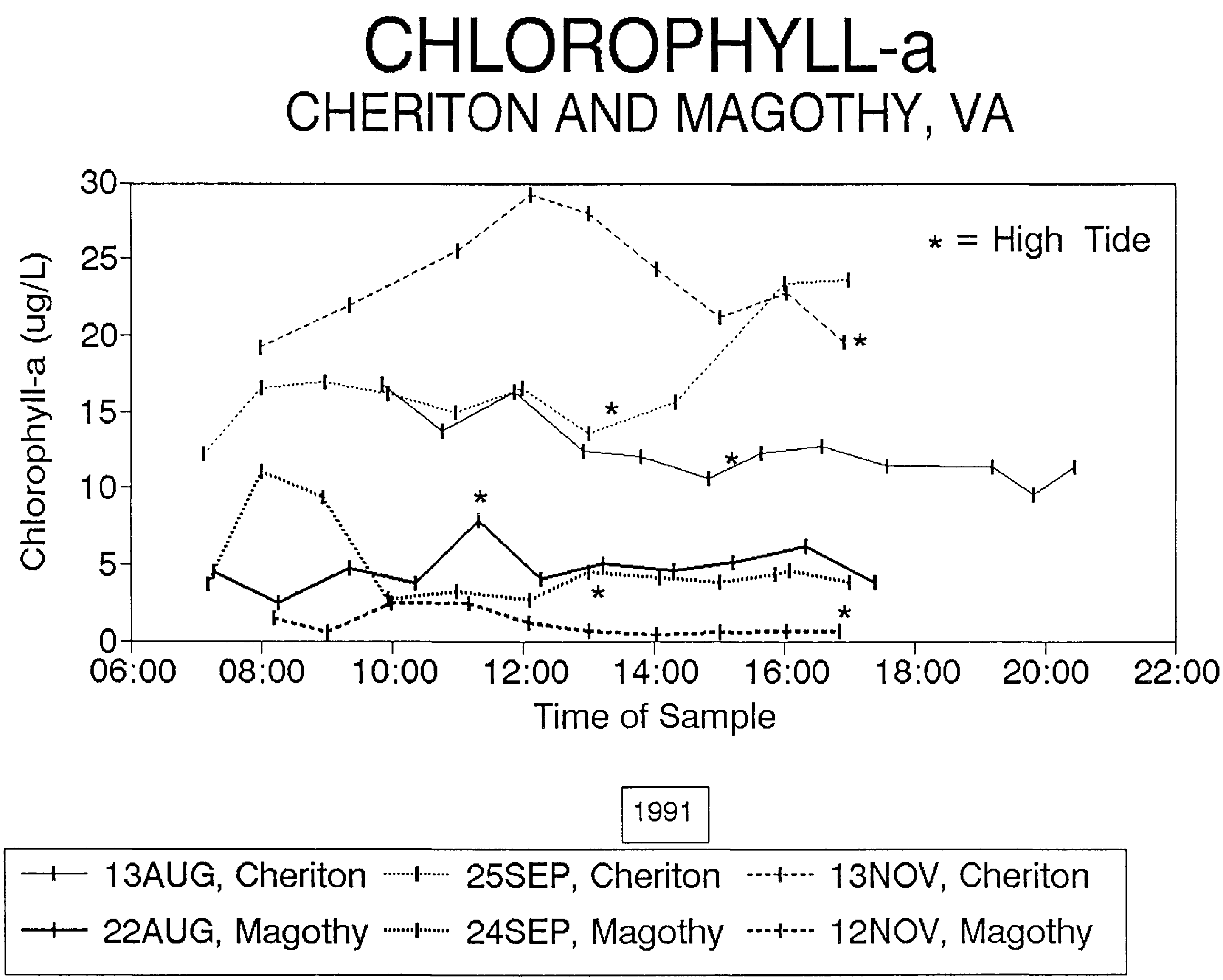

CHLOROPHYLL-a
CHERITON AND MAGOTHY, VA
* = High Tide
Chlorophyll-a (ug/L)
30
25
20
15
10
5
0
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time of Sample
1991
13AUG, Cheriton
25SEP, Cheriton
13NOV, Cheriton
22AUG, Magothy
24SEP, Magothy
12NOV, Magothy

FIGURE 7: Graph of current speeds on October 1, 1991, at Cheriton and Magothy Bay, VA, research sites. Kirby-Smith (1972) found scallop growth inversely proportional to current speed. Although other bids were made to gather more information on current speeds, sudden bouts of bad weather and equipment failures prevented their completion.

CURRENT SPEED

October 1, 1991

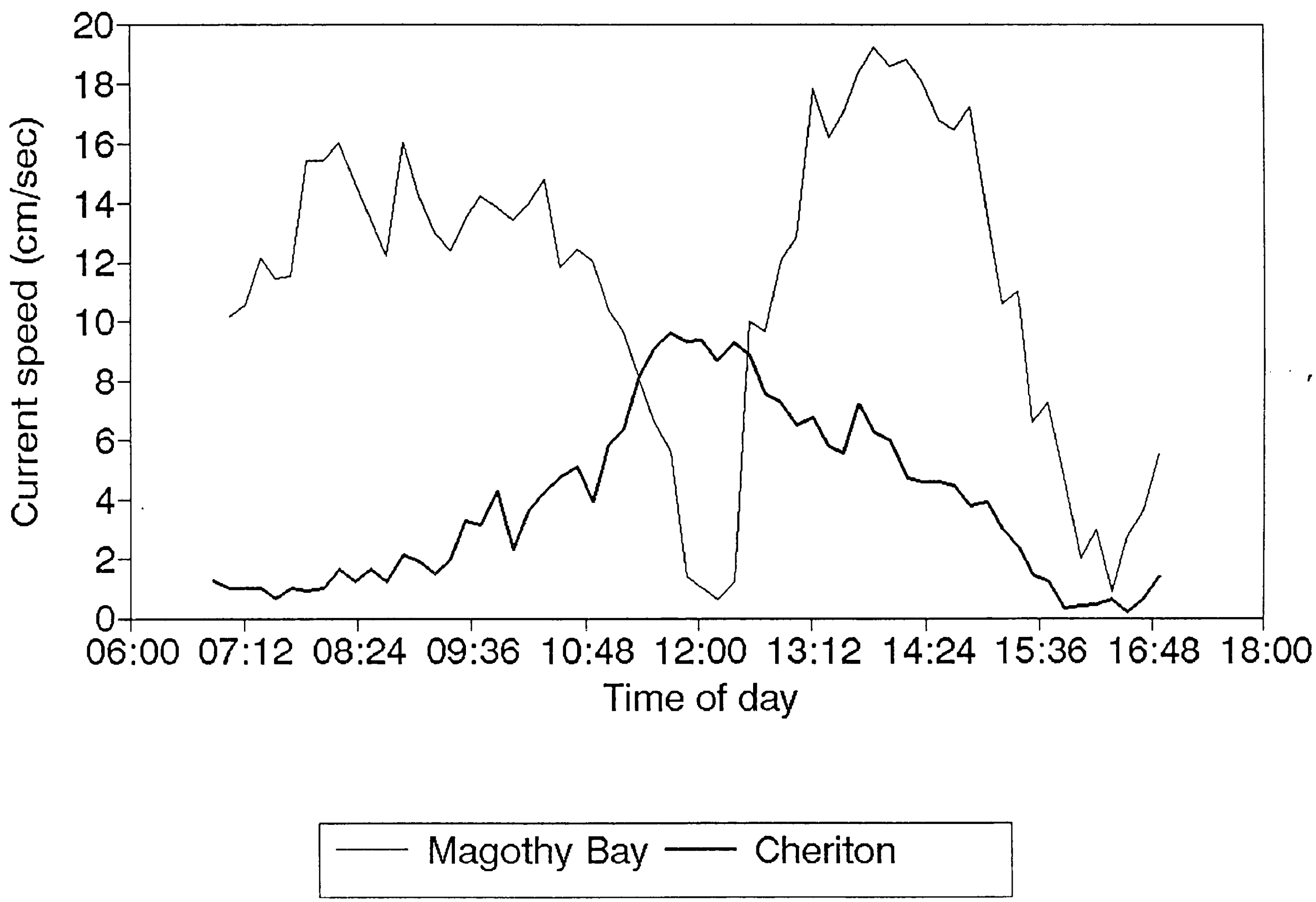


FIGURE 8: Graph of temperature and salinity monitored at the Cheriton and Magothy Bay sites prior to the first harvest. Warmer water enhances growth (Kirby-Smith and Barber 1974). Salinity appeared to make little difference in growth rates in this study (see Results).

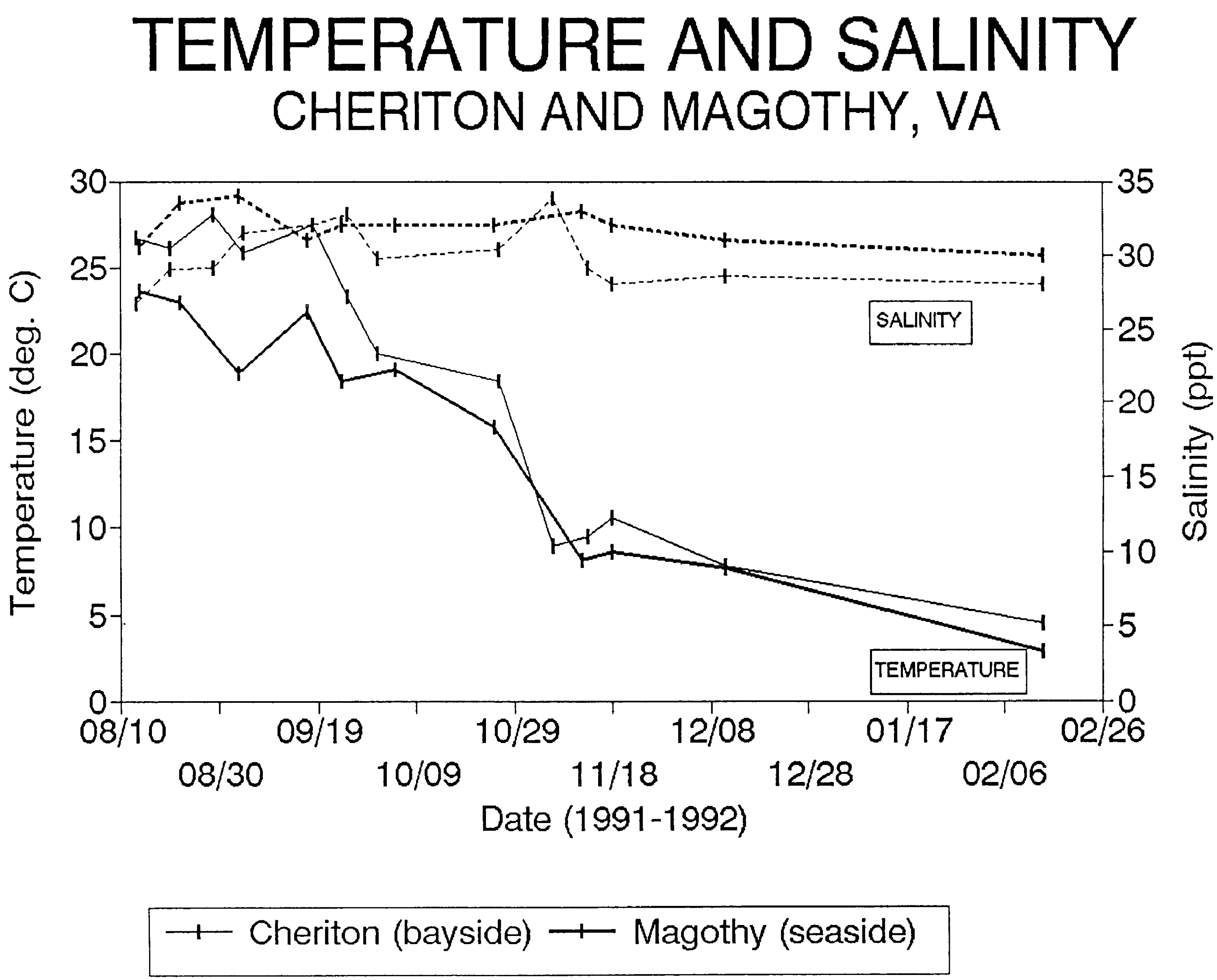

TEMPERATURE AND SALINITY
CHERITON AND MAGOTHY, VA
Temperature (deg. C)
Salinity (ppt)
SALINITY
TEMPERATURE
0
5
10
15
20
25
30
35
08/10
08/30
09/19
10/09
10/29
11/18
12/08
12/28
01/17
02/06
02/26
Date (1991-1992)
Cheriton (bayside)
Magothy (seaside)

FIGURE 9a: Graph of bay scallop shell height growth, averaged by gear type and site.

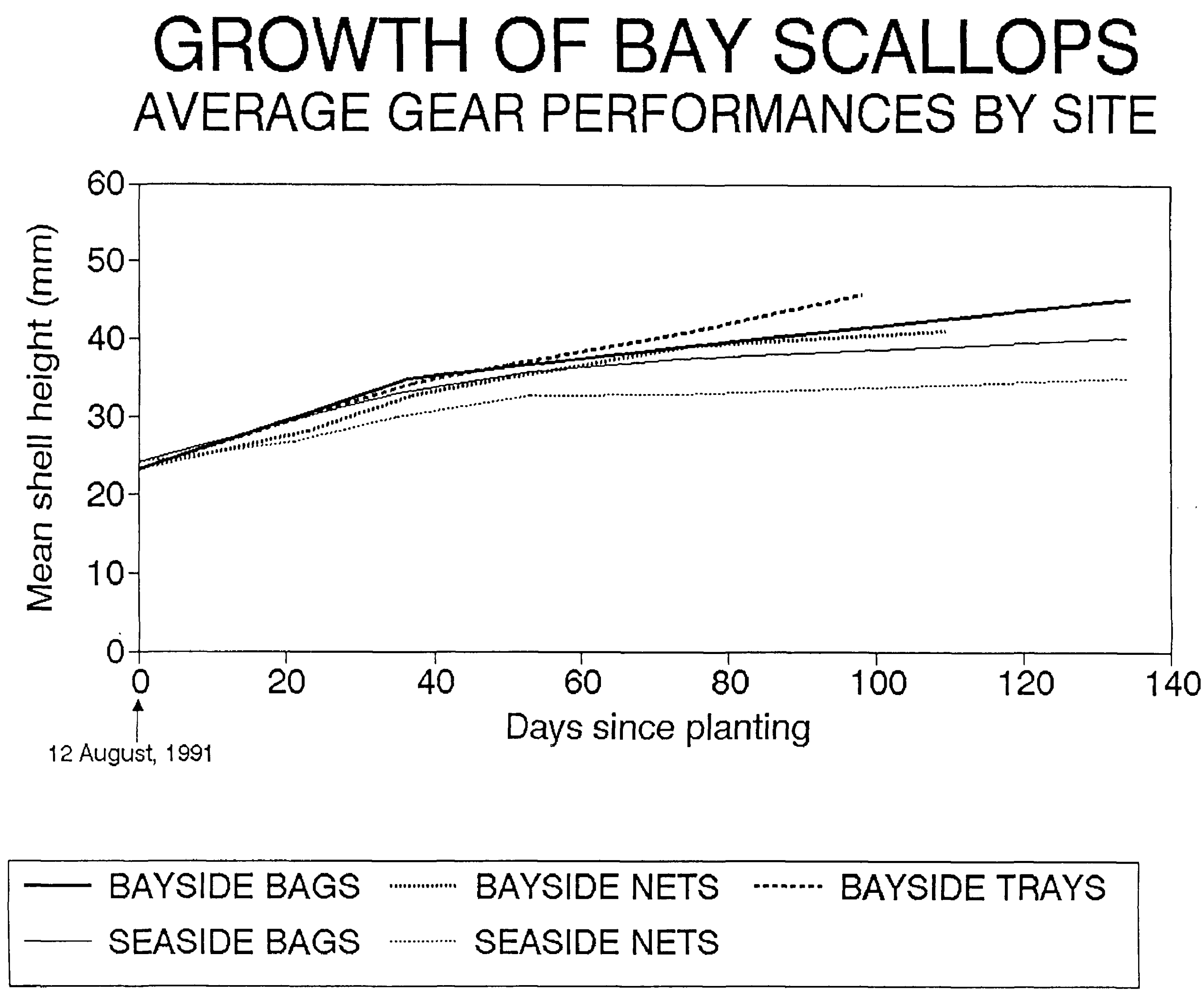
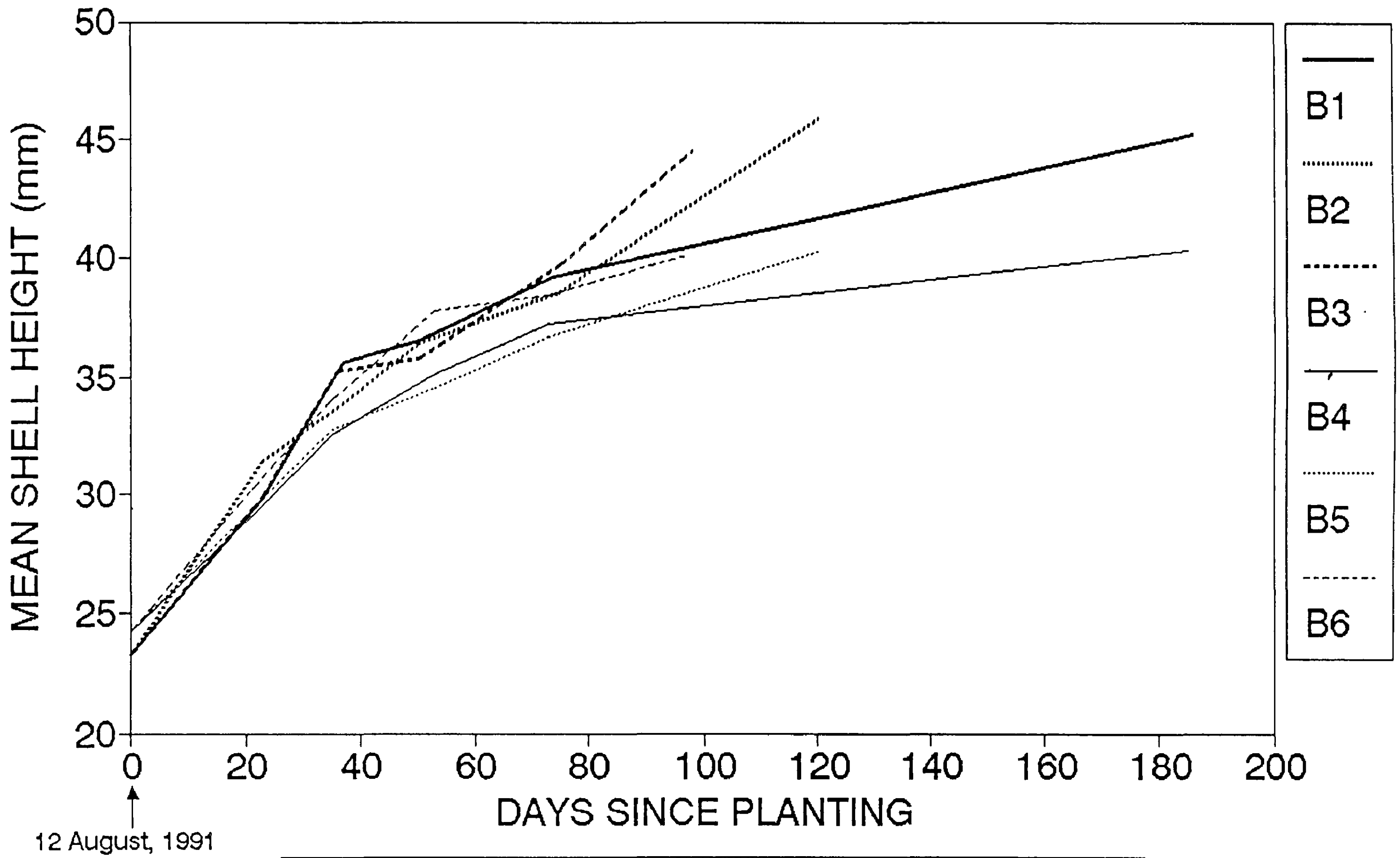

GROWTH OF BAY SCALLOPS
AVERAGE GEAR PERFORMANCES BY SITE
Mean shell height (mm)
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
Days since planting
12 August, 1991
BAYSIDE BAGS
BAYSIDE NETS
BAYSIDE TRAYS
SEASIDE BAGS
SEASIDE NETS

FIGURE 9b: Graph of shell height growth of bay scallops in oyster bags.

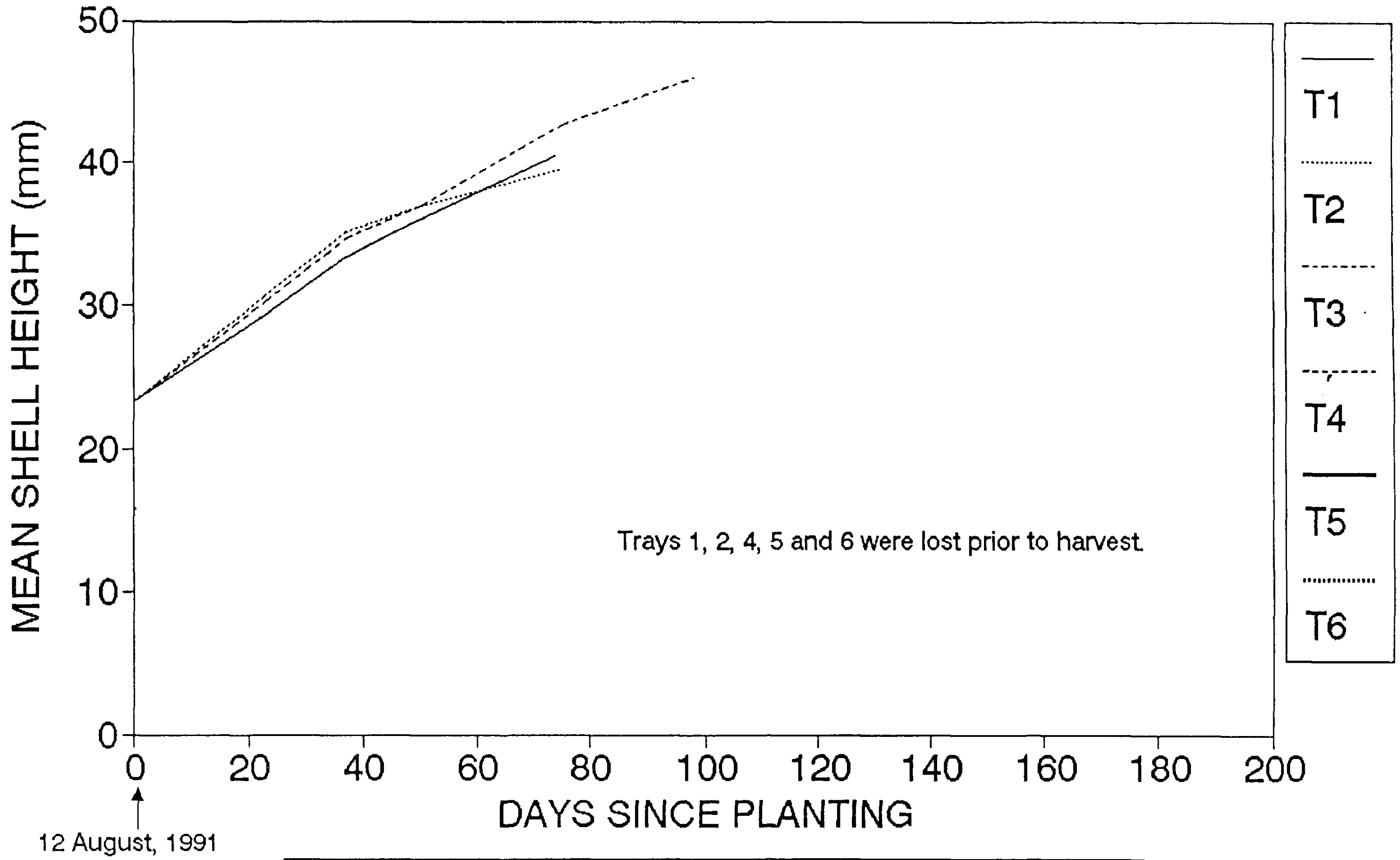
GROWTH OF BAY SCALLOPS
IN OYSTER BAGS



Units 1, 2 and 3 were grown at Cheriton; 4, 5 and 6 were at Magothy Bay, VA.

FIGURE 9c: Graph of shell height growth of bay scallops in trays.

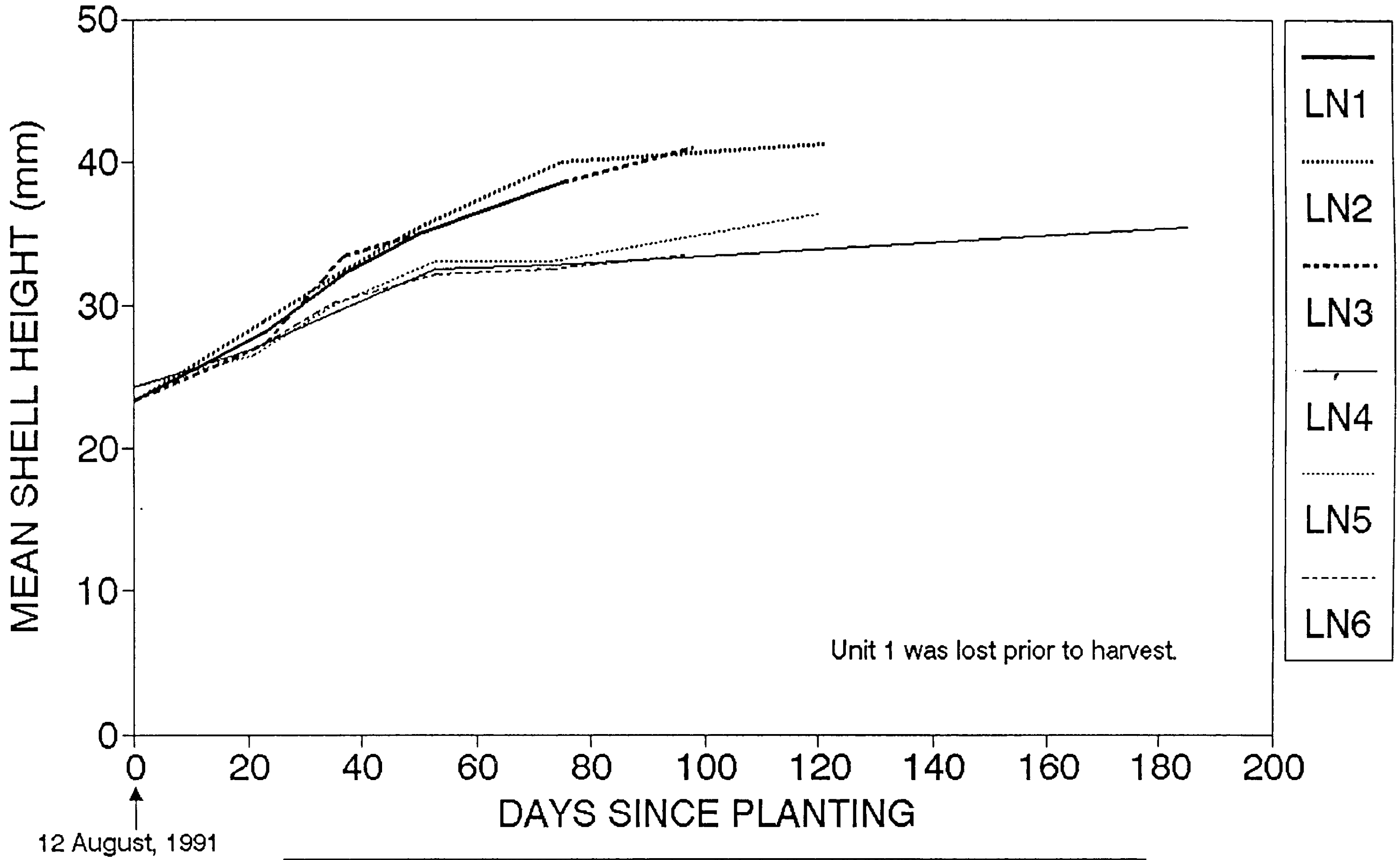
GROWTH OF BAY SCALLOPS
IN TRAYS



Units 1, 2 and 3 were grown at Cheriton; 4, 5 and 6 were at Magothy Bay, VA.

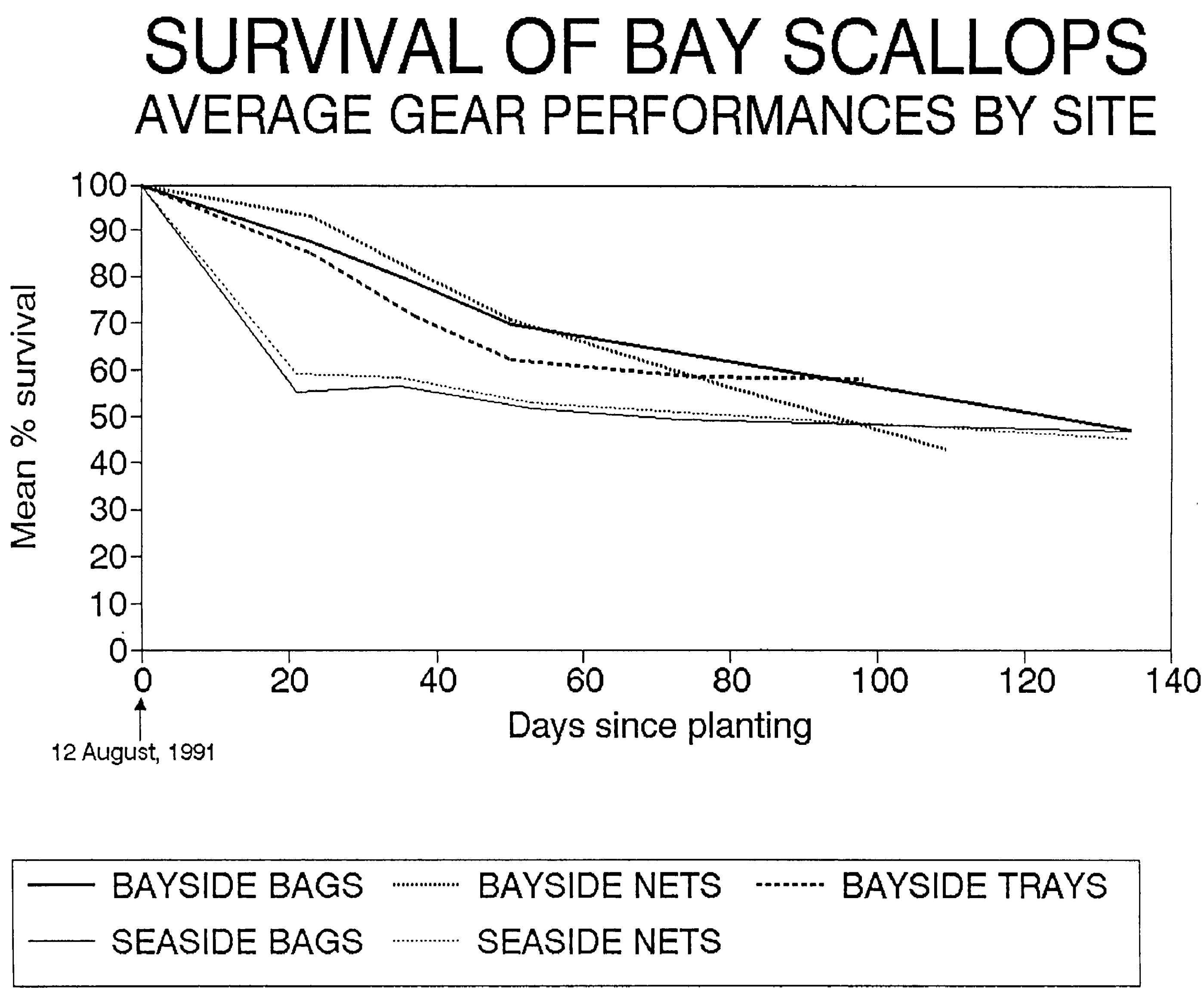
FIGURE 9d: Graph of shell height growth of bay scallops lantern nets.

GROWTH OF BAY SCALLOPS
IN LANTERN NETS



Units 1, 2 and 3 were grown at Cheriton; 4, 5 and 6 were at Magothy Bay, VA.

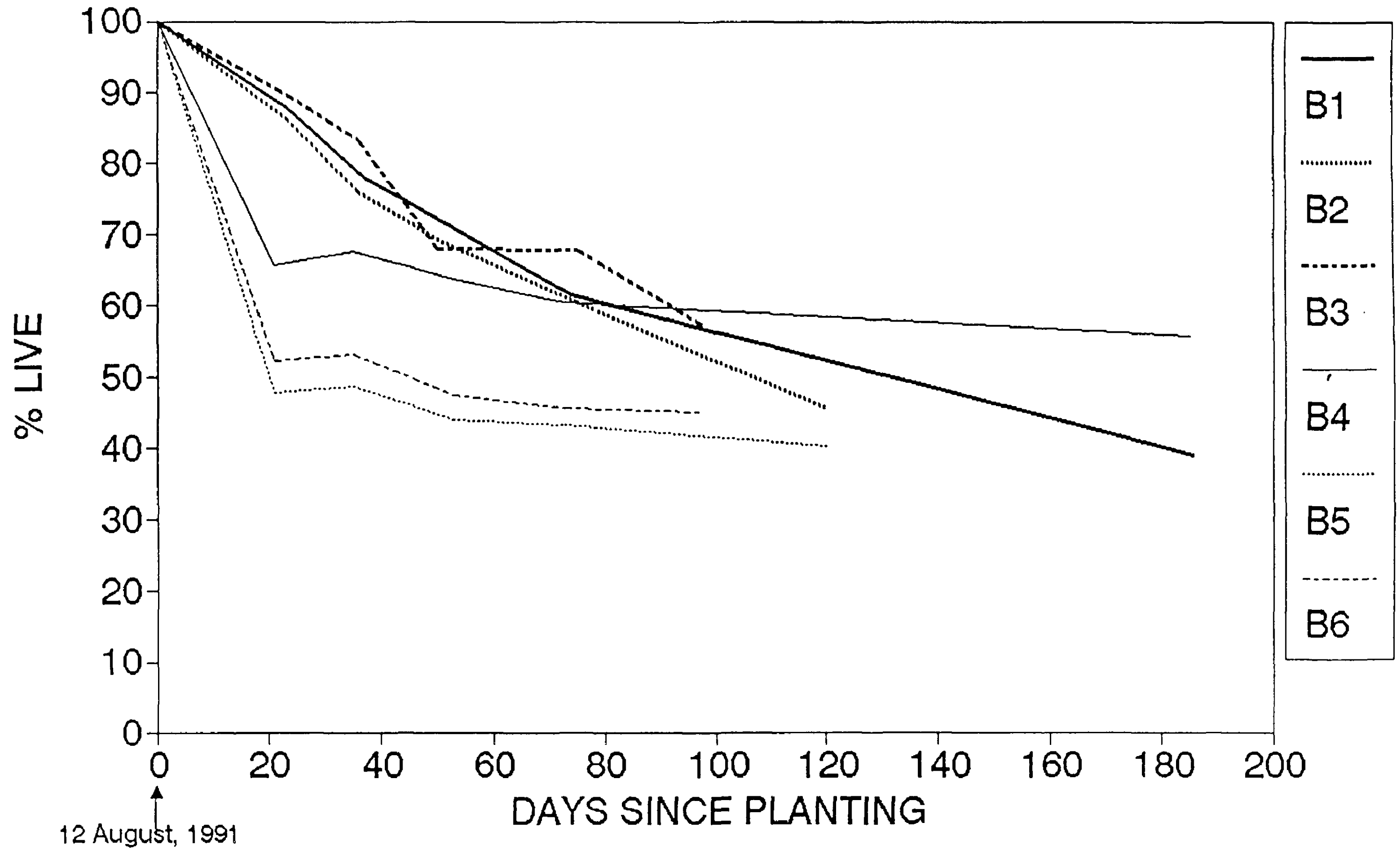
FIGURE 10a: Graph of bay scallop survivorship, averaged by gear type and site.



SURVIVAL OF BAY SCALLOPS
AVERAGE GEAR PERFORMANCES BY SITE
Mean % survival
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
Days since planting
12 August, 1991
BAYSIDE BAGS
BAYSIDE NETS
BAYSIDE TRAYS
SEASIDE BAGS
SEASIDE NETS

FIGURE 10b: Graph of bay scallop survivorship in oyster bags.

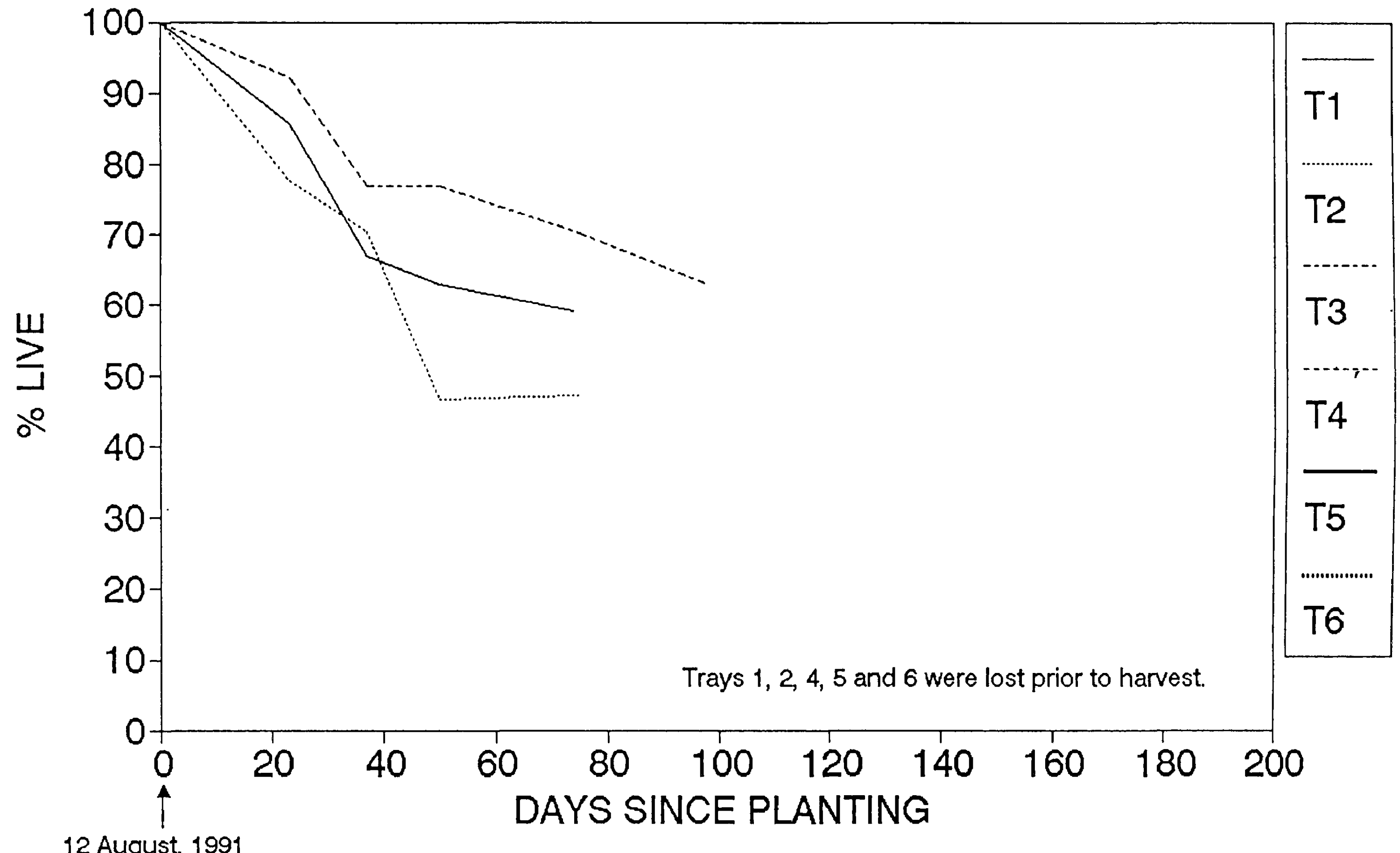
SURVIVORSHIP
OYSTER BAGS



Units 1, 2 and 3 were grown at Cheriton; 4, 5 and 6 were at Magothy Bay, VA.

FIGURE 10c: Graph of bay scallop survivorship in trays.

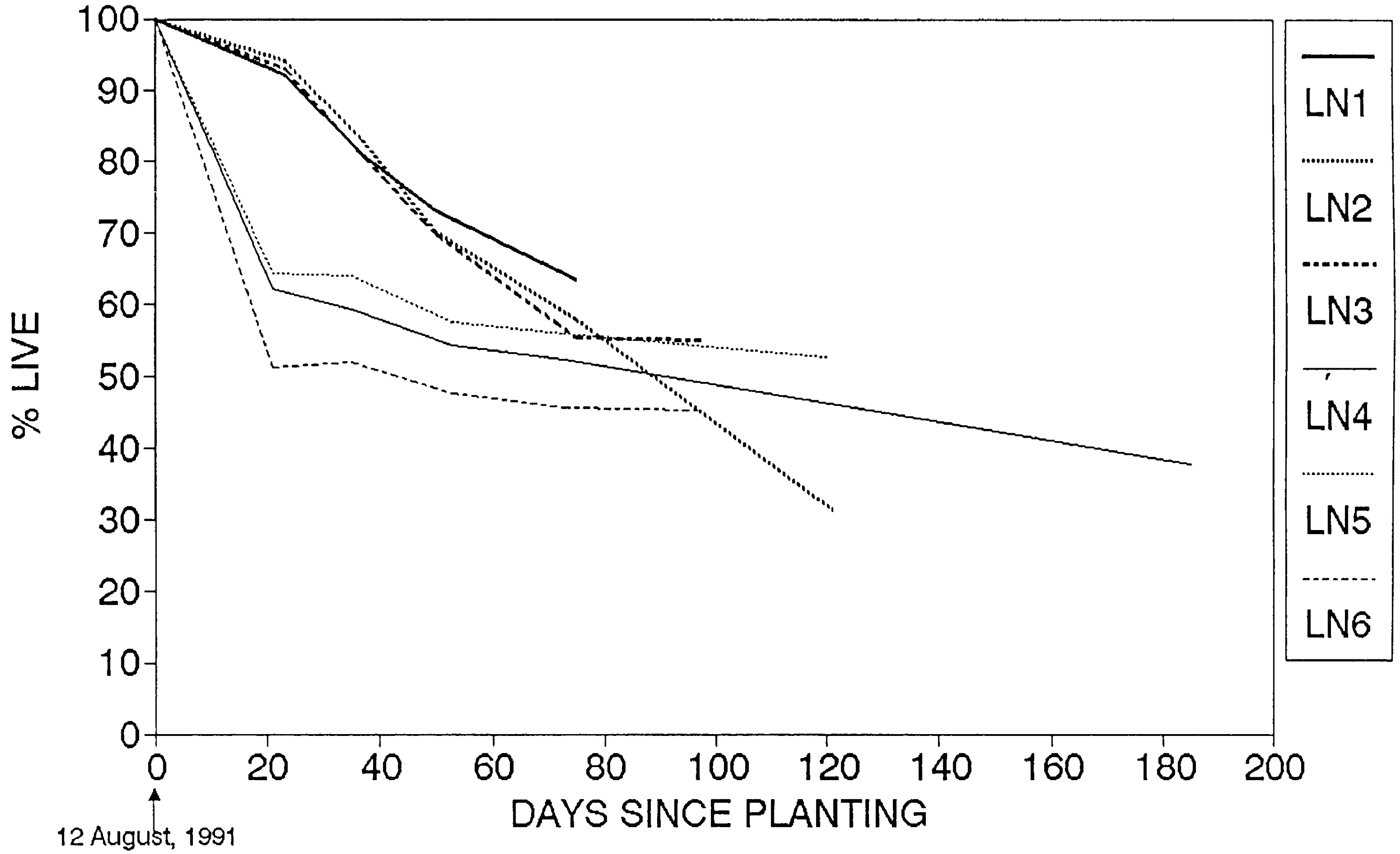
SURVIVORSHIP
TRAYS



Units 1, 2 and 3 were grown at Cheriton; 4, 5 and 6 were at Magothy Bay, VA.

FIGURE 10d: Graph of bay scallop survivorship in lantern nets.

SURVIVORSHIP
LANTERN NETS



Units 1, 2 and 3 were grown at Cheriton; 4, 5 and 6 were at Magothy Bay, VA.

FIGURE 11a: Graph of bay scallop yields, i.e. percent over 40 mm, averaged by gear type and site.

MARKETABLE YIELD

AVERAGE PERFORMANCES OF GEAR BY SITE

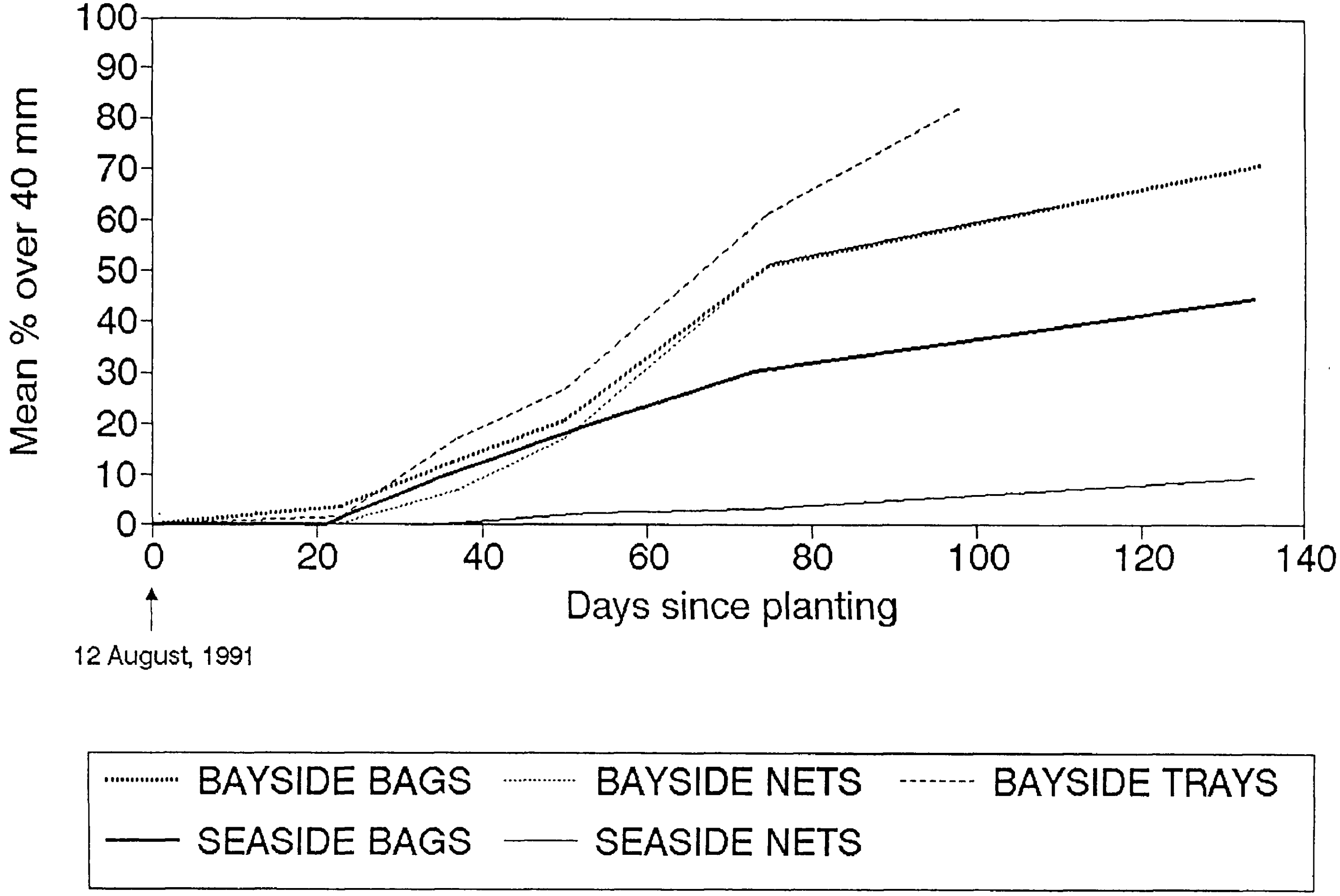
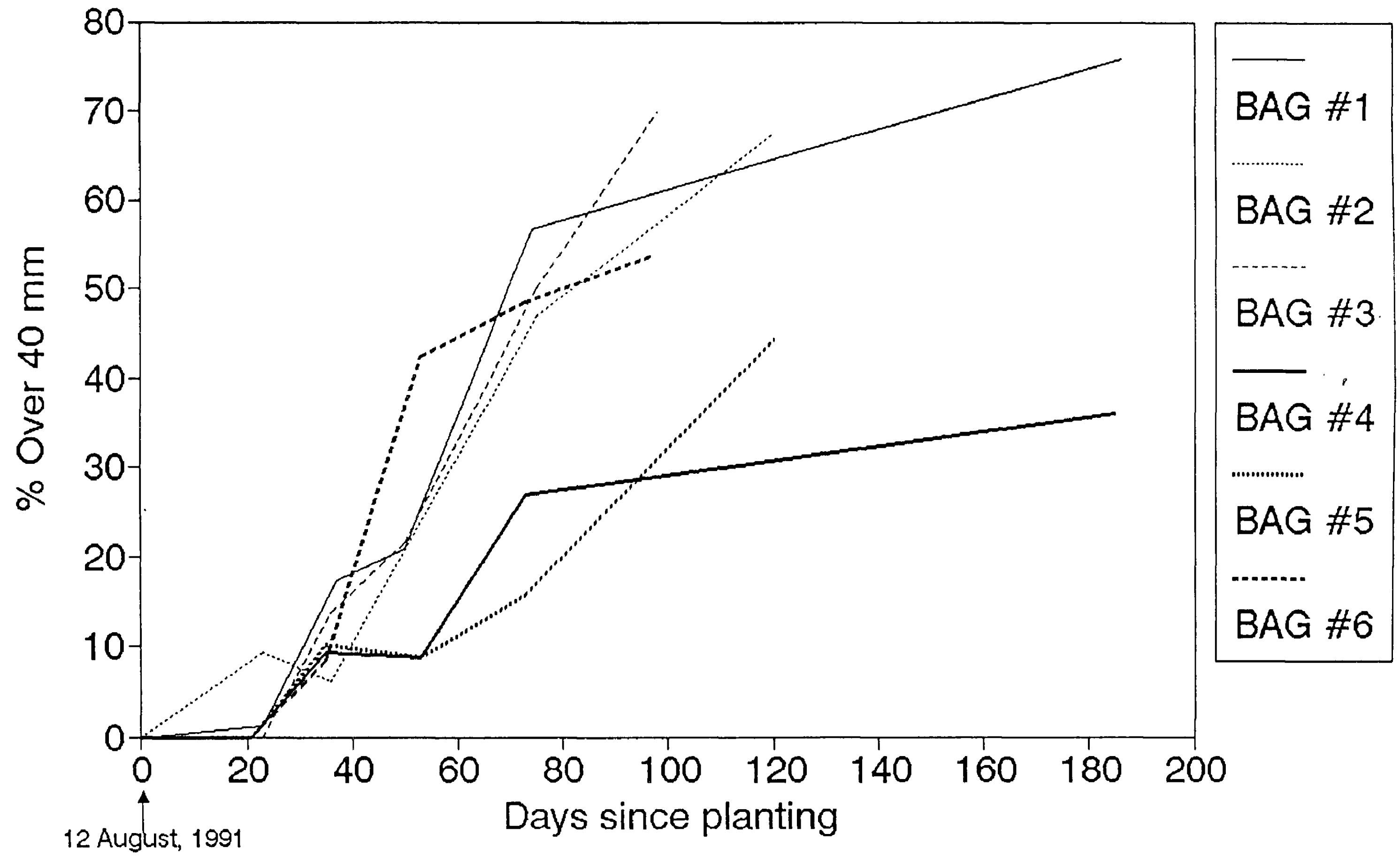


FIGURE 11b: Graph of bay scallop yields over 40 mm in oyster bags.

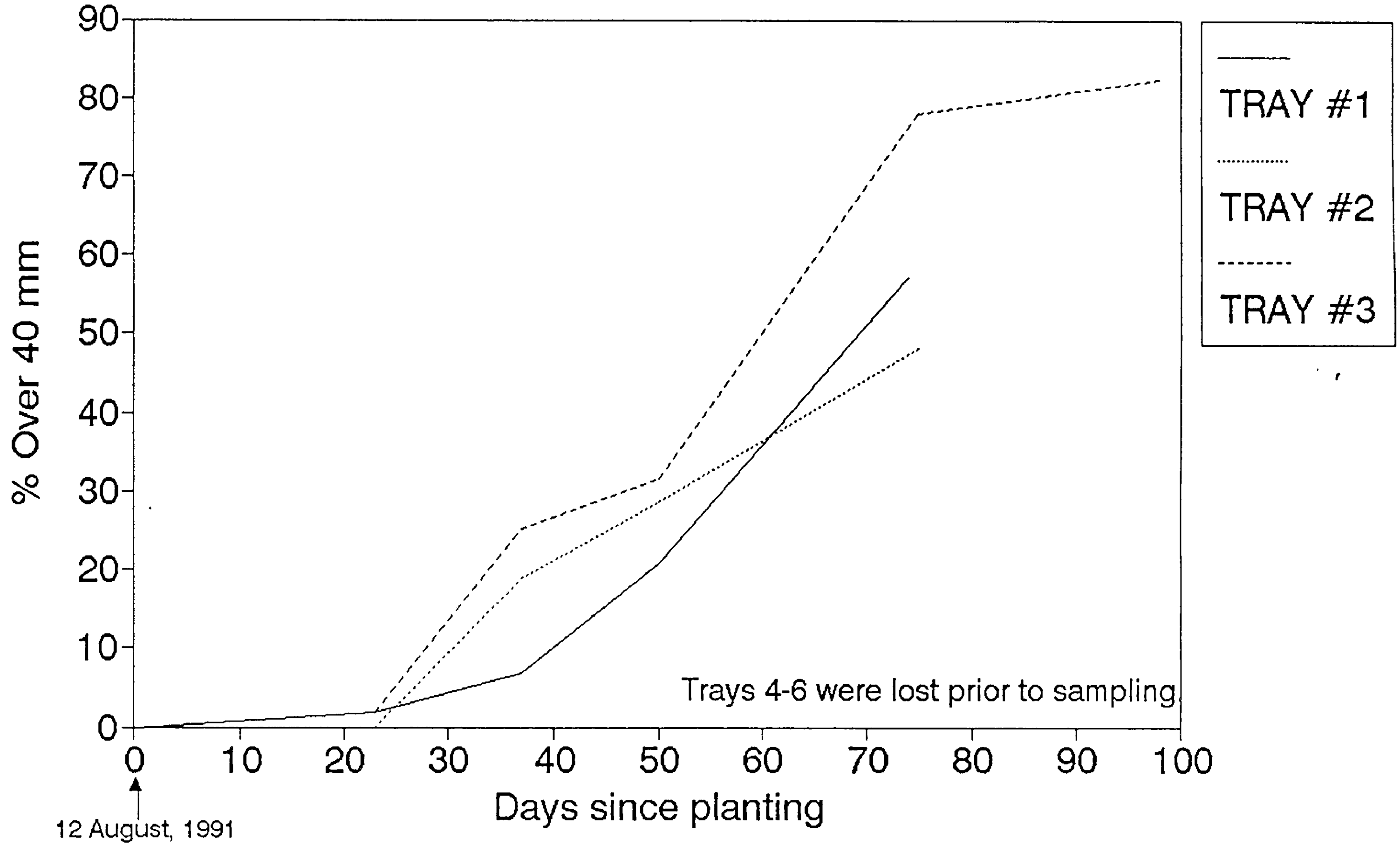
MARKETABLE YIELD
OYSTER BAGS



Units 1, 2 and 3 were grown at Cheriton; 4, 5 and 6 were at Magothy Bay, VA.

FIGURE 11c: Graph of bay scallop yields over 40 mm in trays.

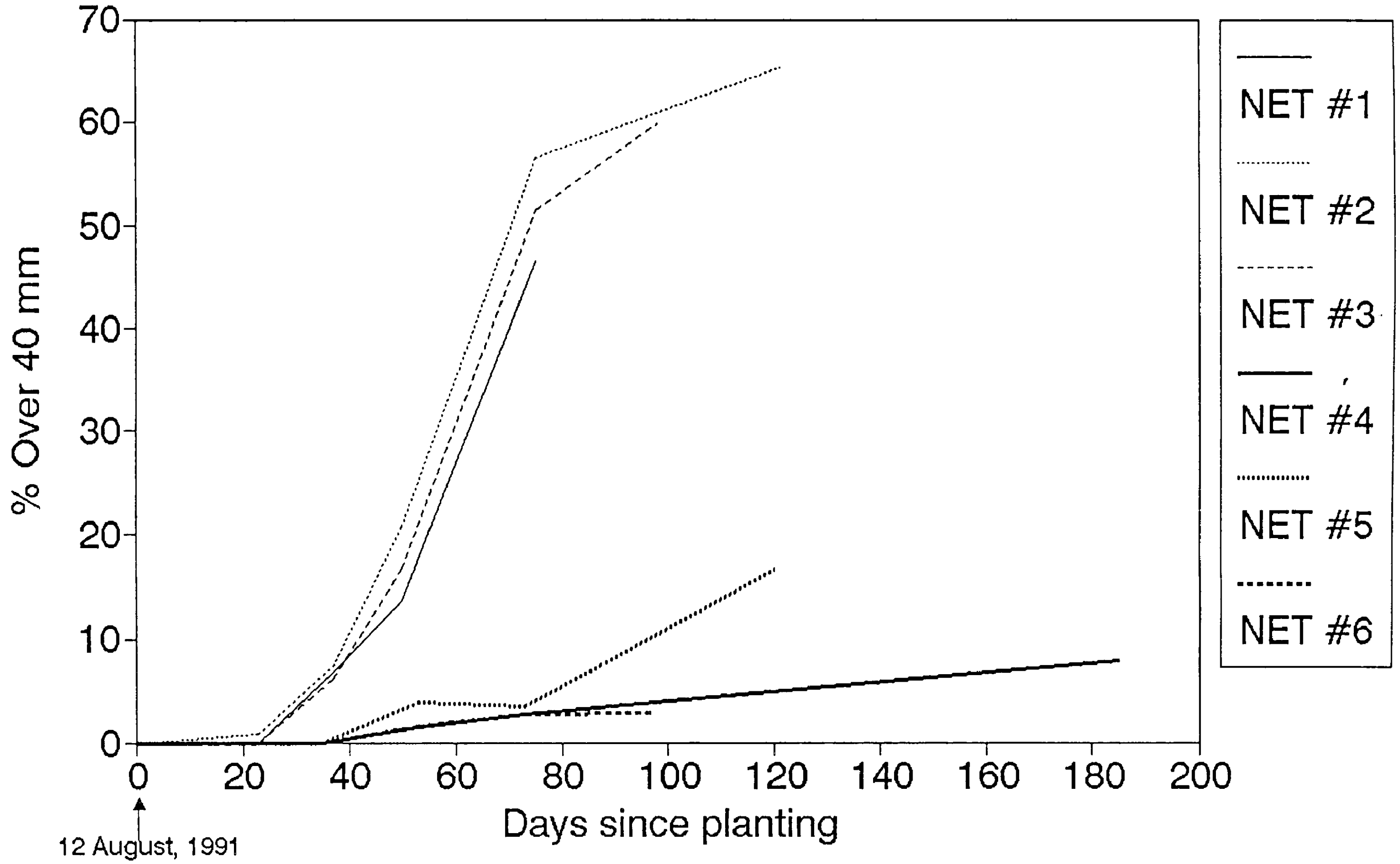
MARKETABLE YIELD
TRAYS



Units 1, 2 and 3 were grown at Cheriton; 4, 5 and 6 were at Magothy Bay, VA.

FIGURE 11d: Graph of bay scallop yields over 40 mm in lantern nets.

MARKETABLE YIELD
LANTERN NETS



Units 1, 2 and 3 were grown at Cheriton; 4, 5 and 6 were at Magothy Bay, VA.

FIGURE 11e: Graph of bay scallop yields over 40 mm at the time of the first harvest (98 days).

MARKETABLE YIELD
AT 98 DAYS

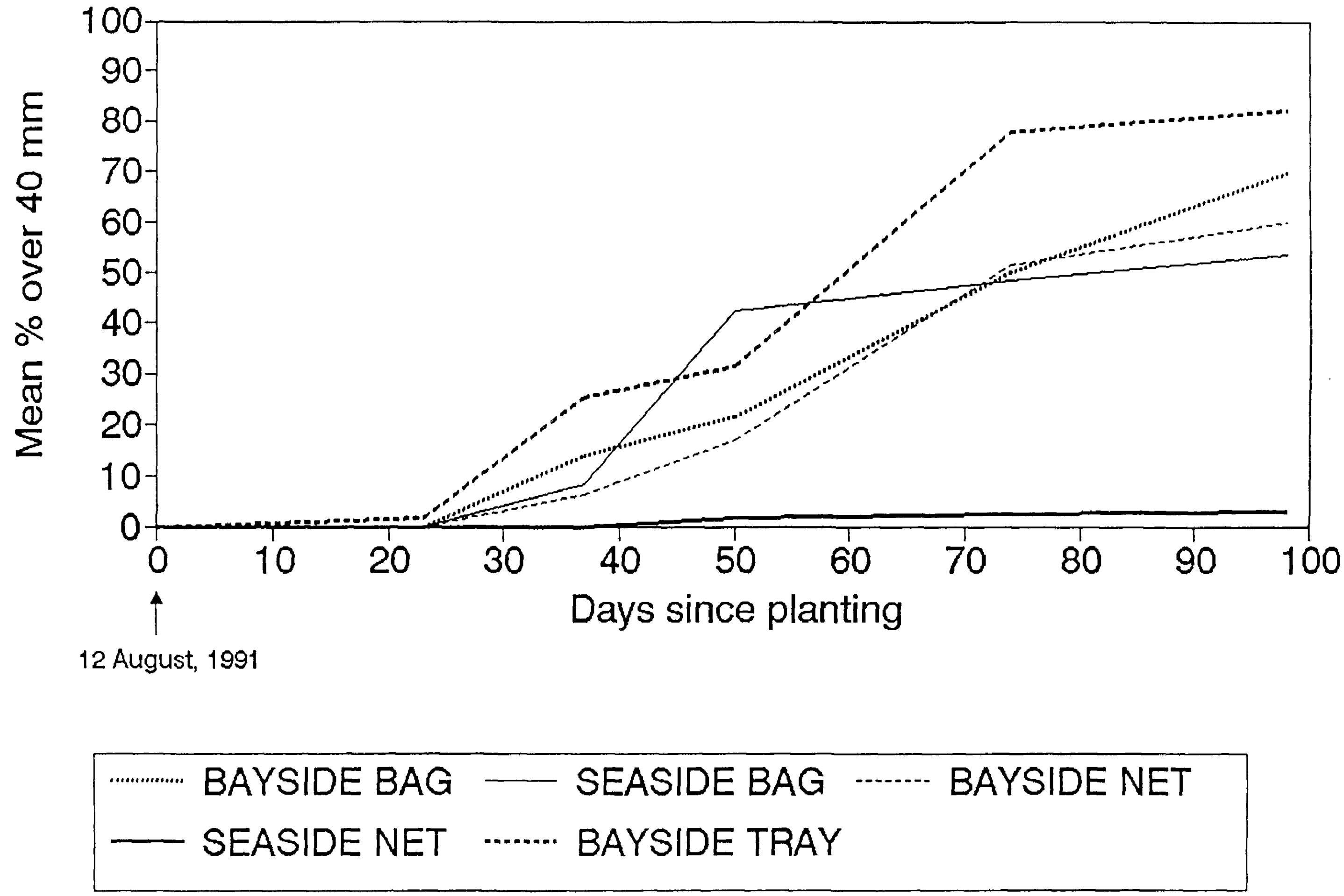


FIGURE 12: Graph of yields (percent above 40 mm) compared with temperature fluctuations averaged by gear type and site.

YIELD vs. TEMPERATURE

AVERAGE PERFORMANCES OF GEAR BY SITE

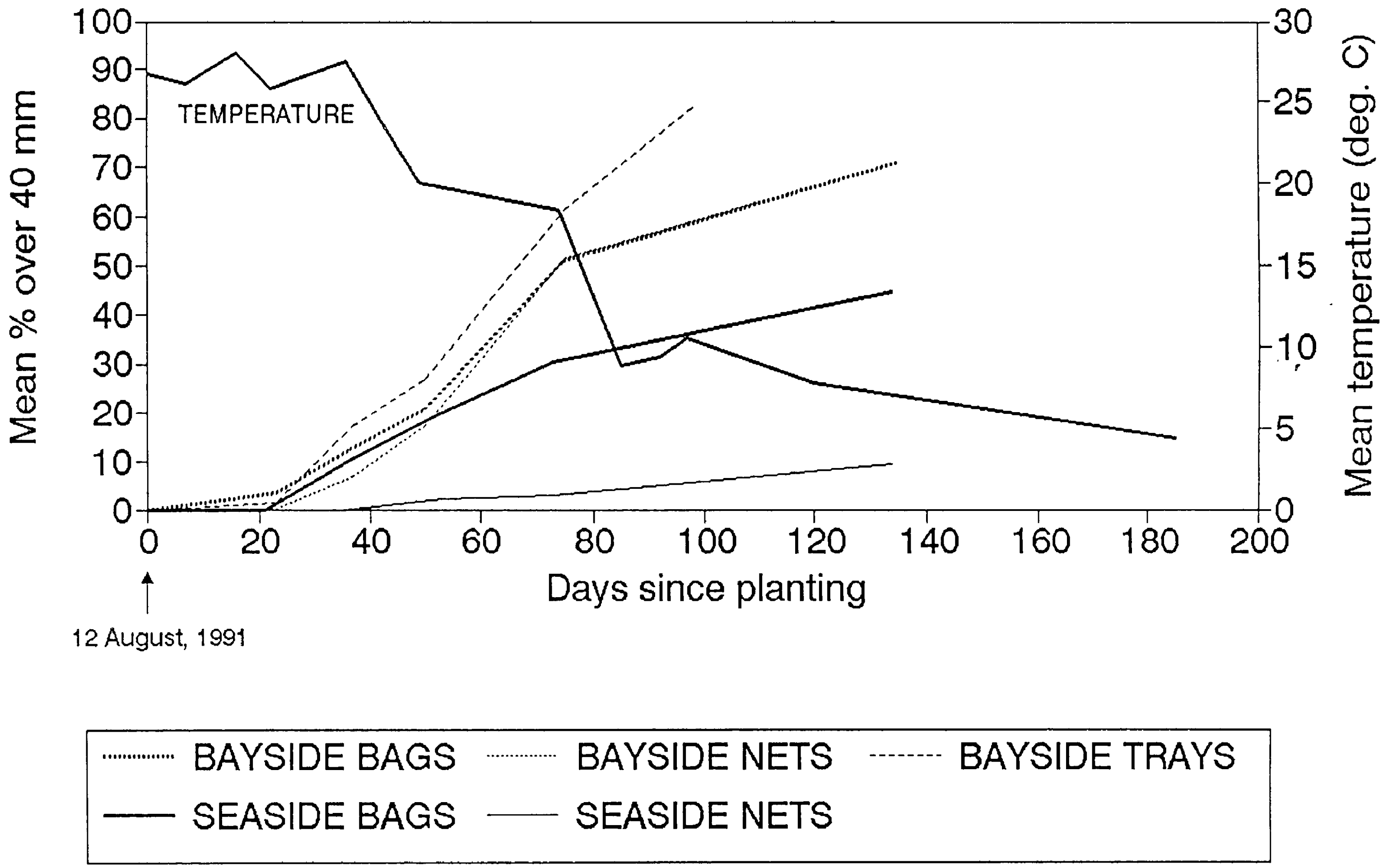
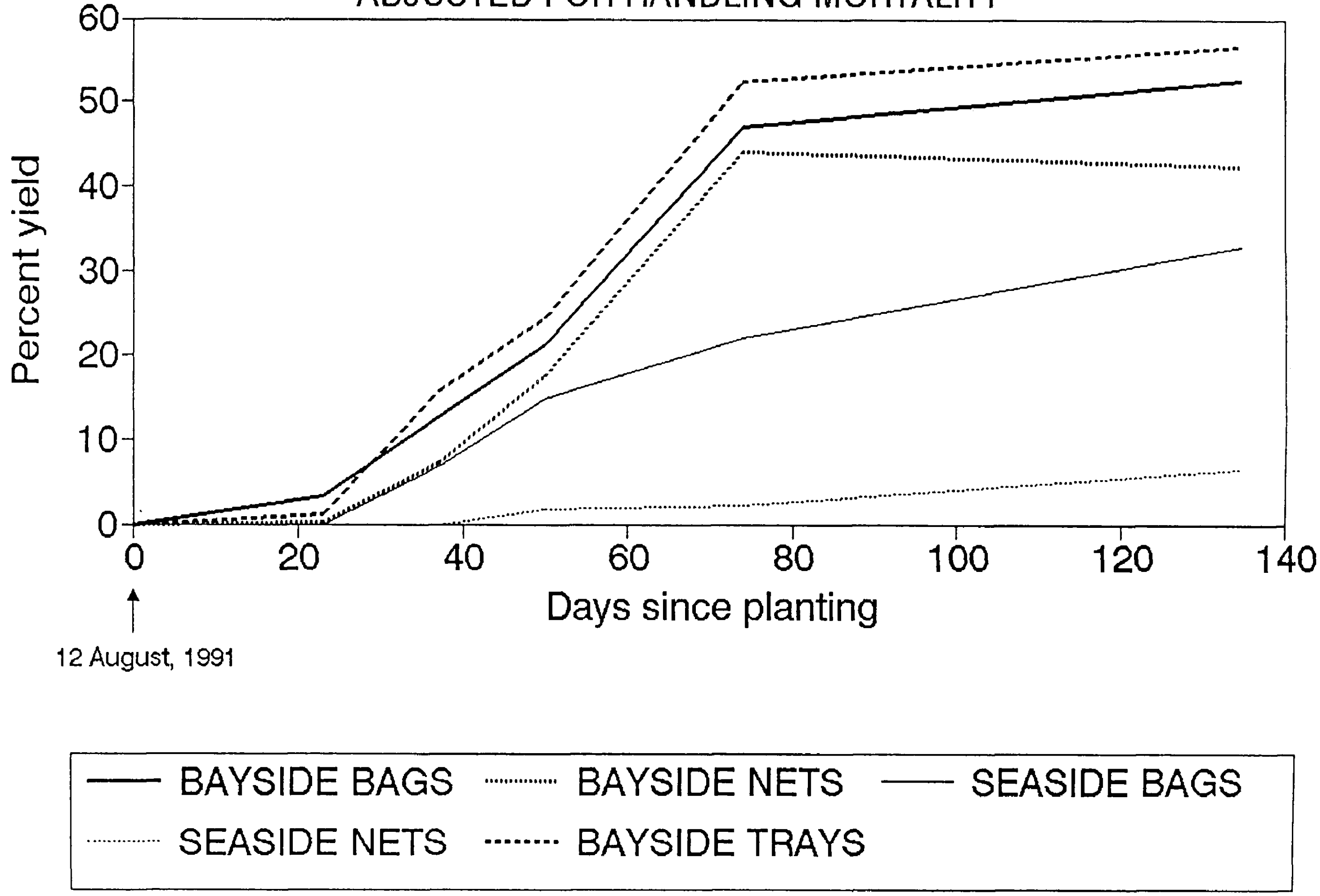


FIGURE 13: Graph of mortality-adjusted yields, average performances of gear by site, as estimated from Oesterling (1992, in press).

YIELD OF SCALLOPS >40 mm

AVERAGE PERFORMANCES OF GEAR BY SITE

ADJUSTED FOR HANDLING MORTALITY



LITERATURE CITED

Alliance for the Chesapeake Bay. 1990. Inside the Chesapeake Bay. In: The Virginia-Pilot and the Ledger-Star, August 6, 1989. Richmond, VA.

Andrews, J.D. 1971. Climatic and ecological settings for growing shellfish. In: Price, K.S., Jr. and D.L. Maurer (eds.). Artificial propagation of commercially valuable shellfish: proceedings of the conference; Oct. 22-23, 1969; University of Delaware. Newark, DE: University of Delaware, College of Marine Studies; (97):107. (Also cited as VIMS Contribution No. 371.)

Anon. 1986. FAO yearbook fishery statistics: catches and landings. Food and Agriculture Organization the United Nations, Rome; (58):149. 503 pp.

Anon. 1990. FAO yearbook fishery statistics: catches and landings. Food and Agriculture Organization the United Nations, Rome; (66):275. 452 pp.

Anon. 1992. Chinese score with scallop introduction. Northeast Fisheries Science Center, Research Highlights, December 1991 to January 1992, NOAA/National Marine Fisheries Service. 1 page.

Barber, N.J., and N.J. Blake. 1981. Energy storage and utilization in relation to gametogenesis in Argopecten irradians concentricus (Say). J. Exp. Mar. Biol. Ecol. pp. 121-134.

Barber, N.J., and N.J. Blake. 1983. Growth and Reproduction of the bay scallop, Argopecten irradians (Lamarck) at its southern distributional limit. J. Exp. Mar. Biol. Ecol. pp. 247-256.

Belding, D.L. 1910a. A report upon the scallop fishery of Massachusetts, including the habits, life history of *Pecten irradians*, its rate of growth, and other factors of economic value. Boston, MA: Special Report of the Commonwealth of Massachusetts Commission on Fisheries and Game. 150 pp., 118 figs.

Belding, D.L. 1910b. The scallop fishery of Massachusetts: including an account of the natural history of the common scallop. Boston, MA: Commonwealth of Massachusetts Commission on Fisheries and Game, Marine Fisheries Series No. 3. 31 pp.

Broom, M.J. 1976. Synopsis of Biological data on scallops (*Chlamys* (*Aequipecten*) *opercularis* (Linnaeus), *Argopecten irradians* (Lamarck), *Argopecten gibbus* (Linnaeus)). FAO Fisheries Synopsis No. 114. 44 pp.

Castagna, M.A. 1983. Review of recent bivalve culture methods. Journal of the World Mariculture Society; (14):567-575. (Also cited as Vims Contribution No. 1134.)

Castagna, M.A. 1975. Culture of the bay scallop, *Argopecten irradians*, in Virginia. Marine Fisheries Review; 37(1):19-24. (MFR Paper 1113).

Castagna, M.A., and W.P. Duggan. 1971. Rearing the bay scallop, *Aequipecten irradians*. Proceeding of the National Shellfisheries Association;(61): 80-85. (Also cited as VIMS Contribution No. 388.)

Castagna, M.A., W.P. Duggan, and D. Garten. 1971. Spawning and rearing the bay scallop: the VIMS laboratory method. Gloucester Point, VA; VIMS, Marine Resources Advisory Series No. 5. 3 pp. (Also cited as VIMS Sea Grant Publication No. VIMS-G1-71-001.)

Chanley, P. 1975. Laboratory cultivation of assorted bivalve mollusks. In: Smith, W.L., and M.H. Chanley (eds.). Culture of marine invertebrate animals: proceedings of the conference; Oct., 1972; Greenport, NY. New York: Plenum Press:297-318

Crenshaw, J.W., J.B. Heffernan and R.L. Walker. 1991. Heritability of growth rate in the southern bay scallop, *Argopecten irradians concentricus* (Say, 1822). Journal of Shellfish Research; 10(1):55-63.

Dore, I. 1990. Bay scallops: a special report. American Seafood Institute Report; (11):20-21.

Duggan, W.P. 1973. Growth and survival of the bay scallop, *Argopecten irradians*, at various locations in the water column and at various densities. Proceedings of the National Shellfisheries Association; (63):68-71. (Also cited as VIMS Sea Grant Publication No. VIMS-R-73-006.)

Epifanio, C.E. 1976. Shell deformity among scallops (*Argopecten irradians* Lamarck) cultured in a recirculating water system. Aquaculture; (9):81-85.

Fay, C.W., R.J. Neves, and G.B. Pardue. 1983. Bay scallop. Washington, DC: U.S. Dept. Interior, Fish and Wildlife Service Species Profile FWS/OBS-82/11.12. 17 pp.

Foster, J. 1990(a). Scallop aquaculture techniques. Practical Aquaculture and Lake Management; 8(1) pp 1-10.

Foster, J. 1990(b). Scallop aquaculture techniques. Practical Aquaculture and Lake Management; 8(2) pp 8-9.

Foster, J. 1990(c). Scallop aquaculture techniques. Practical Aquaculture and Lake Management; 8(3) pp 1-8.

Fusui, Z., H. Yichao, L. Xiangsheng and M. Jianghu. 1988. Mass production of commercial seed bay scallops in China. Institute of Oceanology, Academia Sinica, Qingdao, China. 8 pp.

Gutsell, J.S. 1931. Natural history of the bay scallop. Bulletin of the U.S. Bureau of Fisheries, 1930, vol. 46, Document No. 1100, 1930:569-632.

Graham, R. 1984. Bay scallop mariculture. Underwater Naturalist; 14(4):14-17.

Haas, L. 1990. Methods for chlorophyll-a extraction to determine the timing of the Spring bloom. Virginia Institute of Marine Science internal memorandum. 2 pp.

Heffernan, P.B., R.L. Walker, and D.M. Gillespie. 1988. Biological feasibility of growing the northern bay scallop, *Argopecten irradians irradians* (Lamarck, 1819) in coastal waters of Georgia. Journal of Shellfish Research; 7(1):83-88.

Kelley, K. 1985. The sun shines on Martha's Vineyard shellfish hatchery. Energy Revolution; 12(3):88.

Kelley, K. 1986. An update on the management of the Nantucket bay scallop resource. Shellfish and Marine Department, Nantucket, Massachusetts; 43 p.

Kemp, P.S. 1990. Fact sheet; Feasibility of replenishing bay scallop populations and initiating bay scallop aquaculture. University of North Carolina Sea Grant Marine Advisory Services. 1 page.

Kirby-Smith, W.W. 1969. Growth of the bay scallop *Aequipecten irradians* (Lamarck), as influenced by food concentration and temperature. American Zoologist; 9(4):1144-1145 (abstract no. 550).

Kirby-Smith, W.W. 1972. Growth of the bay scallop: the influence of experimental water currents. Journal of Experimental Marine Biology and Ecology; 8(1):7-18.

Kirby-Smith, W.W., and R.T. Barber. 1974. Suspension feeding aquaculture systems: effects of phytoplankton concentration and temperature on growth of the bay scallop. Aquaculture; (3):135-145.

Loosanoff, V.L., and H.C. Davis. 1963. Rearing of bivalve molluscs. In: Russell, F.S. (ed.). Advances in marine biology. New York: Academic Press; 1-136, 43 figs. (Russell, F.S., Advances in marine biology; vol. 1).

Mann, R. and R. Taylor. 1981. Growth of the bay scallop, *Argopecten irradians*, in a waste recycling aquaculture system. Aquaculture; 24:45-52

Marshall, N. 1956. Studies of the Niantic River, Connecticut, with special reference to the bay scallop *Pecten irradians*. Report to the Waterford-East Lyme (CT) Escallop Commission; 37 pp., 2 appendices.

Marshall, N. 1960. Studies of the Niantic River, Connecticut, with special reference to the bay scallop *Aequipecten irradians*. Limnology and Oceanography; 5(1):86-105. (Also cited as University of Rhode Island, Narragansett Marine Laboratory Contribution No. 26.)

Middleton, K.C. 1983. Bay scallops: a mariculture species whose time has come. Aquaculture Magazine; 9(6):16-20.

Morgan, D.E., J. Goodsell, G.C. Matthiessen, J. Garey, and P. Jacobson. 1980. Release of hatchery-reared bay scallops (*Argopecten irradians*) onto a shallow coastal bottom in Waterford, Connecticut. Proceedings of the Annual Meeting of the World Mariculture Society; (11):247-261.

Mottet, M.G. 1979. A review of the fishery biology and culture of scallops. Olympia, WA: Washington State Dept. of Fisheries Technical Report No. 39. 100 pp.

Mottet, M.G., ed. 1984. Summaries of Japanese papers on hatchery technology and intermediate rearing facilities for clams, scallops, and abalones. Olympia, WA: Washington State Dept. of Fisheries Progress Report No. 203. 86 pp.

Mountain Island (anon.). 1990. Culture of bay scallops. Mountain Island, Nova Scotia, Canada. 2 pp.

Oesterling, M.J. 1992. A review of bay scallop aquaculture techniques in Virginia. Proceedings of the Annual Meeting of the World Aquaculture Society; May 21-25, 1992; Orlando, Florida.

Orth, R.J. 1978. *Zostera marina*. In: J. Court Stevenson and N. Confer (eds.). Pp. 31-57. Summary of available information on Chesapeake Bay submerged vegetation. FWS/035-78/66. August, 1978. 335 pp.

Rhodes, E.W., and J.C. Widman. 1980. Some aspects of the controlled production of the bay scallop (*Argopecten irradians*). Proceedings of the World Mariculture Society 11:235-246.

Rhodes, E.W., R. Goldberg and J.C. Widman. 1981. The role of raceways in mariculture systems for the bay scallop, *Argopecten irradians irradians*, and the surf clam, *Spisula solidissima*. Nursery culturing of bivalve molluscs. Proceedings of the International Workshop on Nursery Culturing of Bivalve Molluscs, Ghent, Belgium, 22-24 February, 1981. pp 227-251. Also in Publications of European Mariculture Society; (7).

Rhodes, E.W., J.C. Widman, P. Boyd. 1981. Experimental evaluation of nursery and grow-out methods for the bay scallop, *Argopecten irradians*. Charlottendun, Denmark: International Council for the Exploration of the Sea, C.M.1981/F:25. 14 pp.

Risser, A.M. 1981. Habits and life history of the scallop (*Pecten irradians*); preliminary report. 31st Report of the Commission of Island Fisheries, State of Rhode Island and Providence Plantations; pp. 47-55.

Russell, H.J., Jr. 1973. An experimental seed bay scallop stocking of selected Rhode Island waters. Providence, RI: Rhode Island Dept. of Natural Resources, Division of Fish and Wildlife Report. 82 pp.

Sanders, M.J. 1973. Culture of the scallop, *Patinopecten yessoensis* (Jay) in Japan. Fisheries Contribution; 29:1-24.

Sastry, A. 1961. Studies on the bay scallop, *Aequipecten irradians concentricus* Say, in Alligator Harbor, Florida. Tallahassee, FL: Florida State University. 118 pp. Dissertation.

Spitsbergen, D.L. 1977. A study of the bay scallop (*Argopecten irradians*) in North Carolina waters. Morehead City, NC: North Carolina Dept. of Natural Resources and Community Development, Annual Progress Report on Project No. 2-256-R-2 to U.S. Dept. of Commerce. 22 pp.

Tabarini, C.L. 1983. Induced triploidy in the bay scallop, *Argopecten irradians*, and its effect on gametogenesis. Aquaculture 42(2):151-160.

Townshend, E.R., and J.M. Worms. 1983. Introduction of a new pectinid species *Argopecten irradians irradians* to the Gulf of St. Lawrence, Canada. International Council for the Exploration of the Sea, Shellfish Committee Report, 9 p.

Walker, R.L., P.B. Heffernan, J.W. Crenshaw and J. Hoats. 1991a. Effects of mesh size, stocking density and depth on the growth and survival of pearl net cultured bay scallops, *Argopecten irradians concentricus* in shrimp ponds in South Carolina, U.S.A. Journal of Shellfish Research; 10(2):465-470.

Walker, R.L., P.B. Heffernan, J.W. Crenshaw and J. Hoats. 1991b. Mariculture of the southern bay scallop, *Argopecten irradians concentricus*, in the southeastern U.S. Journal of the World Aquaculture Society. (In press).

Walsh, D. 1981. Limitations and potentials of bay scallop (*Argopecten irradians*) culture in New England. Journal of Shellfish Research; 1(1):125-126.

Widman, J.C., E.W. Rhodes and P.A. Boyd. 1983. Nursery culture of the bay scallop *Argopecten irradians irradians* (Lamarck) in suspended mesh enclosures. Journal of Shellfish Research; 3(1):104.

Widman, J.C. 1991. Nursery culture of the bay scallop, *Argopecten irradians irradians*, in suspended mesh nets. Aquaculture, (99):257-267.

Zhang, F., Y. He, X. Liu, J. Ma, S. Li, L. Qi, M. Guan and Z. Wang. 1987. A report on the experimental cultivation of bay scallop and kelp by turn. Marine Science/Haiyang Kexue; (6):1-6.

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