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ABUNDANCE AND BIOMASS OF WEATHERVANE SCALLOPS IN KAMISHAK BAY, ALASKA, 1996

by

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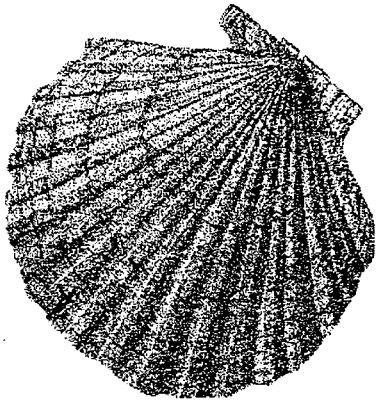

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ABSTRACT

During 7-9 July 1996, the Alaska Department of Fish and Game conducted an area-swept survey of the weathervane scallop *Patinopecten caurinus* bed located in Kamishak Bay, Alaska. A total of twenty-six 1.0-nautical mile (1,855 m) tows were successfully completed using a systematic sample design and a 2.4-m (8-ft) wide dredge with 10.2-cm (4-inch) rings and a 3.8-cm (1.5-inch) liner. Scallop catches in individual tows ranged from 0-165 kg (0-364 lb) per tow; mean catch was 62.97 kg (138.7 lb) per nautical mile. Mean weight of individual scallops ranged from 50-600 g (0.13-1.33 lb) within tows, and was 300 g (0.58 lb) among all tows. Scallop ages ranged from young-of-the-year age 0+ to age 24. Scallops age 5 and younger comprised 51% of the survey population. Age-4 was the most abundant cohort, although age-1, -3, and –12 scallops each comprised over 10% of the population. Size-at-age indicated asymptotic growth with annual growth rates decreasing rapidly after around age 5. Under an assumption of survey dredge catchability equal to 1.0, the point estimate and 95% confidence interval for weathervane scallops in Kachemak Bay was 2,485 ± 914 metric tons (5.5 ± 2.0 million lb). Estimated population abundance was 3.2 million scallops. Mean meat recovery was 8.54% of whole scallop weight. The Kachemak Bay fishery for weathervane scallops is annually managed for a guideline harvest range of 53-106 metric tons (10,000-20,000 lb) of meats. Management for the upper end of the range in the 1996 fishery would represent a harvest rate of 4.3% of the estimated standing stock.

INTRODUCTION

The commercial fishery for weathervane scallops *Patinopecten caurinus* in Kamishak Bay, Alaska dates to 1983 when the Alaska Board of Fisheries directed the Alaska Department of Fish and Game (ADF&G) to allow restricted exploratory scallop fishing (Kimker 1994*a*). Fisheries in 1983 and 1984 had limited participation, partly due to the following restrictions:

1. Gear was limited to a 1.8-m (6-ft) wide dredge with a minimum ring size of 10.2 cm (4 in), inside diameter.
2. Only one unit of gear could be deployed at a time.
3. A logbook had to be completed and returned.
4. Vessels had to check-in with the Homer office before and after each trip.
5. An observer had to be taken upon the vessel if requested by the department.

Based on a 1984 ADF&G survey (Hammarstrom and Merritt 1985) and preliminary fisheries catch data, the Alaska Board of Fisheries in 1985 adopted a guideline harvest level (GHL) of 4.5-9.1 metric tons (mt; 10,000-20,000 lb) of shucked scallop meats and a 15 August to 31 October fishing season.

Annual harvest increased from 1.1 mt (2,346 lb) of shucked meats in 1983 to 7.0 mt (15,364 lb) in 1986, and corresponding catch per unit of effort (CPUE) increased from 9.8-16.4 kg (21.5-36.2 lb) of shucked meats/h (Table 1). However, initial fishing in 1987 yielded an unexpectedly low CPUE of 6.8 kg (15.1 lb) of shucked meats/h, and the fishery was closed with a catch of only 163.3 kg (360 lb) of shucked meats (Kimker 1994*a*). Anecdotal information indicated the Kamishak Bay scallop bed was illegally fished between the 1986 and 1987 seasons (Al Kimker, ADF&G, Homer, AK, personal communication). Although fishing was allowed during the 1988-1992 seasons, no vessels fished because ADF&G, lacking fishery-independent assessments, could not guarantee that the fishery would remain open long enough to allow more than a single delivery.

In 1993, ADF&G acted to protect dwindling crab resources by setting bycatch limits in the scallop fishery at 0.5% of the estimated populations of king or Tanner crabs. The 1993 harvest yielded 9.1 mt (20,115 lb) of shucked meats from 15 deliveries by three vessels, while the 1994 harvest yielded 9.3 mt (20,431 lb) of shucked meats from 11 deliveries by four vessels. In the spring of 1995, the National Marine Fisheries Service closed federal waters off Alaska to scallop fishing following the identification of a regulatory problem. Existing regulations allowed unrestricted fishing by vessels not registered with the state of Alaska (National Marine Fisheries Service, News Release Nos. 95-20, 95-61, and 95-91, Juneau, AK). Because the Kamishak Bay scallop bed is located in federal waters, no fishing occurred in 1995. Amended federal regulations allowed commercial fishing to resume in 1996.

Prior to 1996, weathervane scallops in Kamishak Bay had only been surveyed in 1984. Fishery catch rates increased between 1983 and 1986, and catch rates in 1993 and 1994 were some of the highest since the fishery began (Table 1). Because the fishery was closed in 1995, and catch rates were high in 1993 and 1994, the scallop fleet requested the GHL be raised for 1996. However, observed CPUE increases may have been a function of increased fishing power rather than increased scallop abundance. Due to changes in fishing technology, application of recent CPUE values to the 1984 relationship between CPUE and population abundance may overestimate the true population. In addition, age frequencies of weathervane scallops in commercial catches from Kamishak Bay have often been multimodal with a primary peak in abundance for 5- to 7-year-old scallops and a secondary peak for age-11 to -13 scallops (Bechtol 2000). However, the 1993 and 1994 fisheries showed unimodal age distributions with a dominant age-8 cohort in 1993 becoming dominant age-9 scallops in 1994.

A fishery-independent survey of Kamishak Bay scallops was needed to allow ADF&G to set a 1996 GHL appropriate to current population size and to adequately assess the status of pre-recruit scallops. This report documents methods used to conduct the 1996 weathervane scallop survey in Kamishak Bay and the rationale behind recommendations for the 1996 commercial fishery GHL.

Survey Objectives

1. Determine the abundance, age, size, and sexual maturity of weathervane scallops caught by a 2.4-m (8-ft) dredge with 10.2-cm (4-in) inside diameter rings and a 3.8-cm (1.5-in) liner.

2. Estimate meat recovery by age group.

3. Determine the relative bycatch of king and Tanner crabs and other non-scallop species.

4. Calculate a GHR based on the current estimated population size, and evaluate changes in scallop distribution and density since the 1984 survey.

5. Estimate scallop catchability in the 2.4-m (8-ft) dredge using a video camera.

Study area

Although weathervane scallops are found throughout the Kamishak Bay District, the majority of the fished population is aggregated in a limited area or bed located east of Augustine Island (Figure 1). This study, as well as a previous survey, focused on this aggregation (Hammarstrom and Merritt 1985; unpublished data). The scallop bed occurs on flat or gradually sloping bottom ranging from 30-90 m (20-50 fathoms) in depth with muddy or sand substrate interspersed with shale outcroppings.

METHODS

Vessel and Gear

The state research vessel *Pandalus* conducted the survey during 6-12 July 1996. The *Pandalus* has an overall length of 20.2 m (66 ft), a displacement of 100 mt, and is powered by a 365 hp diesel engine. Survey staff included 3-4 biologist and 3 vessel crewmembers.

The 1984 survey was conducted with a 2.4-m (8-ft) dredge having a retainer bag consisting of 7.6-cm (3-in) inside diameter rings. To capture small scallops, the retainer bag was fitted with a 3.8-cm (1.5-in) mesh liner. Weathervane scallop catchability with this dredge was assumed equal to 1.0 such that all scallops larger than the liner stretch mesh were retained (Hammarstrom and Merritt 1985). However, data from a paired-tow study using different dredges off Kayak Island, Alaska in 1995 suggested that this assumption may not have been true (Charles Trowbridge, ADF&G, Homer, AK, unpublished data). Average catch per meter of dredge width was less for the 2.4-m dredge than for a 4.6-m (15-ft) commercial dredge.

In a cooperative effort between ADF&G and the fishing industry, the 1996 Kamishak Bay survey used a dredge provided by Kodiak Fish Company. This dredge had the same 2.4-m width as was used for the 1995 survey and was also fitted with a 3.8-cm mesh liner to retain small weathervane scallops. However, the new dredge was equipped with a heavier sweep chain and a retainer bag with larger 10.2-cm (4-in) inside diameter rings. Vessel tow speed was approximately 7,421 m/h (4.0 nautical miles per h = 4.0 nmi/h) and the cable scope (ratio of cable to bottom depth) was about 4:1.

To examine scallop catchability by the dredge, an underwater video camera provided by the National Marine Fisheries Service was used to estimate the proportion of scallops in the path of the dredge that were retained. Previous efforts to mount a camera on the steel frame of the original 2.4-m dredge during a 1995 survey at Kayak Island were unsuccessful because the camera and frame attachment altered the dredge dynamics, causing the dredge to invert when deployed. For the 1996 Kamishak Bay survey, the camera and battery were attached to the dredge tow wire approximately 2 m in front of the dredge.

Study Design

Sample Area

The 1984 survey encompassed a 56 square nautical mile (nmi^2; 1.0 nmi = 1,855 m = 6,076 ft) study area, divided into 1-nmi^2 grids, and sampled a total of 47 stations (Figure 2). Based on

scallop catches during the 1994 and 1995 trawl surveys for king and Tanner crabs, we believed the Kamishak Bay scallop bed now covers a larger area than was sampled in 1984 (Kimker 1994*b*, 1996). In fact, the most abundant scallop catches in the trawl survey occurred southeast of the 1984 scallop survey area.

Our goal for 1996 was to sample scallops with 1-nmi tows from 50 stations. For consistency with the 1984 Kamishak Bay scallop survey, the 1996 survey area was also delineated into 1-nmi^2 grids. A secondary goal was to expand the sample stations into the area southeast of Augustine Island.

Survey Design

To allow greater survey coverage and identification of the scallop bed distribution, an adaptive, systematic survey design was used with the total survey area divided into a primary area, which encompassed the 1984 survey area, and a secondary area, which included an additional scallop aggregation detected by ADF&G trawl surveys. Sample stations were defined by overlaying a grid of 1.0-nmi squares over the study areas (Figure 3). For each area; a systematic design with two primary units was used in which alternate stations were identified for potential sampling. The primary sample unit was randomly selected, so there was equal probability of selecting either unit. The vessel skipper, in cooperation with the project leader, determined the specific tow location within each sample station. The dredge was towed for a distance of approximately 1.0 nmi within the sample station. Under the adaptive design, stations were added if catch in an adjacent station exceeded 6.8 kg (15 lb) of whole scallops, which was approximately 6% of the highest station catch observed during the 1984 survey (Figure 2). Thus, the 6.8-kg catch level was used to define the bed margin within an area. The systematic pattern of sampling alternate survey stations was preserved when expanding survey area margins. Thirty-five stations in the primary area and 30 stations in the secondary area were initially identified for as the potential pool for sampling in 1996.

For animal populations with individuals that are randomly distributed, a single systematic sample provides good variance estimates. Because weathervane scallops have a patchy distribution and are not uniformly clustered within beds, a systematic sample tends to overestimate the population variance (Thompson 1987). However, we decided to forego precision about the variance estimate in order to equally distribute sampling effort across the survey area and better define weathervane scallop bed boundaries.

Data Collection

During each tow, the vessel captain recorded the following:

1. sequential tow identification number;
2. alphanumeric station code;
3. date;
4. tow start and stop location (latitude and longitude);

5. tow compass heading;
6. vessel speed;
7. tow start and stop time;
8. distance towed;
9. maximum and minimum depth;
10. sea conditions;
11. amount of cable deployed (scope); and
12. gear performance.

Upon completion of each tow, the catch was washed clean of mud and then separated into weathervane scallops, weathervane scallop shells, fish, crab, and other bycatch, including debris. Commercially important crab species were examined to determine carapace width, shell age, and sex, and discarded. Fish were weighed, enumerated by major species group, and discarded. Debris, assorted invertebrates, and any remaining bycatch were weighed and their relative contribution visually estimated (e.g., 60% starfish and 40% rocks).

Weathervane Scallop Sampling

Total live weight and numbers of weathervane scallops, including broken shells with attached viscera, were recorded. Weathervane scallop shells and shell fragments without attached viscera were weighed and discarded. Empty weathervane scallop shells with both valves connected by an intact ligament (referred to as cluckers), were cleaned, measured (shell height), aged, labeled, and retained for archival.

Ten adult weathervane scallops were randomly selected from each tow, placed intact into a plastic bag, and frozen. These were taken back to the ADF&G Homer laboratory to examine the relationship between recovered meat (i.e. the large adductor muscle, referred to as the "quick" by the fishing industry) and age class. Twenty randomly selected weathervane scallops were weighed and shucked aboard the vessel. Their meats were placed into a container, and their dorsal shells were cleaned, labeled, measured, aged, and placed in storage for later age verification. A sample size of at least 600 scallops was desired to achieve a predetermined precision in the estimated age class proportions (Thompson 1987). Non-random samples of immature weathervane scallops from each tow were also shucked, cleaned, measured, aged, and stored for representative age verification. When possible, shell heights of at least 70 of the weathervane scallops remaining from a tow were captured with an electronic measuring board to construct height frequency distributions.

Fresh weathervane scallop meat recovery was estimated each day from whole weight of the approximately twenty scallops sampled from each tow and the weight of their shucked meats. Mean fresh meat recovery was estimated as pooled meat weight divided by pooled whole weathervane scallop weight.

Frozen weathervane scallop meat recovery was estimated from samples returned to the ADF&G Homer laboratory. These samples were thawed and shucked, and the empty shell was cleaned, measured for height, and aged.

Data Analysis

For each tow, weathervane scallop age and size composition data were pooled for both fresh and frozen samples and results applied to all weathervane scallops captured in that tow. Age and size data, weighted by within-tow sample size, were pooled among all successful tows to estimate population age and size compositions. Shell height-at-age, L_t, and scallop weight-at-age, W_t, were modeled with the following von Bertalanffy growth equations (Ricker 1975):

$$L_t = L_\infty(1-e^{-K_l(t-t_{0,l})}) \quad , \tag{1}$$

$$W_t = [W_\infty(1-e^{-K_w(t-t_{0,w})})]^3 \quad , \tag{2}$$

where

K_l is the constant relative rate of growth in length,
K_W is the constant relative rate of growth in weight,
t is age (time) in years,
$t_{0,l}$ is the age of theoretical zero length,
$t_{0,w}$ is the age of theoretical zero weight,
L_∞ is the theoretical mean maximum length, and
W_∞ is the theoretical mean maximum weight.

The Microsoft Excel Solver utility was used to minimize sums of squares while adjusting the constant growth rates, t_0's, and theoretical mean maximum sizes in each of the above equations.

The weathervane scallop population estimate derived from the 1996 Kamishak Bay survey was based on area-swept calculations (Sokal and Rolf 1969; Gunderson 1993), similar to estimates for previous weathervane scallop surveys in southcentral Alaska (Hammarstrom and Merritt 1985; Charles Trowbridge, ADF&G, Homer, Alaska, personal communication). Mean catch per nautical mile ($\bar{c}$) and it's variance (s^2) were calculated by

$$\bar{c} = \frac{\sum_{i=1}^{n} \frac{c_i}{d_i}}{n} \quad , \tag{3}$$

and

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{c_i}{d_i} - \bar{c}\right) \quad , \tag{4}$$

where

c_i is the catch of a species, either as abundance or weight, in sample tow i,
d_i is the distance towed in nautical miles for sample tow i, and
n is the number of stations sampled.

An estimate of the population (P) was calculated by expanding $\bar{c}$ over the surveyed area as

$$P = \left(\frac{6{,}076}{8}\right) N\bar{c} \quad , \tag{5}$$

where

6,076 is the length in feet of a nautical mile,
8 is the width of the dredge in feet, and
N is number of possible survey grids within the survey area.

Variance of the surveyed population was estimated by

$$Var(P) = N^2\left(\frac{N-n}{N}\right)\left(\frac{6{,}076}{8}\right)^2 \frac{s^2}{n} \quad . \tag{6}$$

For these estimates, calculations were applied to the scallop bed as assumed to be defined by the adaptive survey design and incorporating the scallop distribution as indicated by the 1984 survey (Hammarstrom and Merritt 1985).

The confidence interval was constructed as

$$P \pm t_{(0.975;n-1)}\sqrt{Var(\ P)} \quad . \tag{8}$$

Support frames on the scallop dredge divided the dredge into four equal sections, each 0.62 m (2 ft) wide. The field of view in the underwater video tape recordings captured only the center two portions of the dredge. To assess scallop catchability in the dredge, an observer replayed the video and counted scallops observed passing into the left-center quarter of the dredge, then replayed the video counting scallops passing into the right-center quarter of the dredge. A total of two observers reviewed the tapes. For each tow, counts were averaged among quarters and observers, than expanded by a factor of four for comparison to actual dredge catches. Catchability was set equal to 1.0 for this study (see Results – Catchability).

RESULTS

A total of 26 successful tows, each 1.0 nmi in length, were made during the 7-9 July 1996 survey of weathervane scallops in Kamishak Bay (Table 2; Figure 4). Although more days and stations were scheduled for the survey, inclement weather prevented additional survey work within the available time and tide series. Thus, only the primary survey area was assessed. One additional tow was repeated because it was determined upon dredge retrieval that the dredge had inverted during the initial attempt. Tow speeds during the survey ranged from 6,493-7,607 m/h (3.5-4.1 nmi/h) and individual tow duration lasted from 15-23 min. The surveyed water depths ranged from 37-59 m (20-32 fathoms).

For the 23 successful tows, the aggregate weight of material retained by the survey dredge totaled 4,549 kg (10,019 lb). Catch weights of individual tows ranged from 13-614 kg (29-1,353 lb). Debris, primarily mud and gravel, accounted for 2,772 kg (6,112 lb), or 61% of the aggregate survey catch, although debris contribution to individual tows ranged from 7.5-99.9%.

Weathervane Scallops

Catchability

Underwater video recordings were made of six dredge tows during the Kamishak Bay scallop survey (Table 3). The survey dredge inverted on tow 96016, possibly because the bridle attachment for the video camera slid down the cable toward the dredge, which may have affected dredge dynamics. In the interest of optimizing survey time, the camera was not immediately reattached on the replicate of tow 96016. On tow 96023, the videotape ended prior to completion of the tow. As a result, only four tows, 96008, 96011, 96019, and 96025, were analyzed for comparison to dredge catches, and the second observer did not examine tow 96008. Preliminary review of video recordings from scallop tows indicated limited agreement of scallop abundance between estimates by video observers and dredge catches. Greater dredge catches of scallops generally corresponded with greater observer counts. However, after expanding for the unobserved portion for the dredge, video counts typically exceeded dredge catches at high scallop catch tows. Because all scallops are not equally visible to a video observer, it would also be expected that observer detection of a scallop increases as a function of scallop shell height. Because of the small sample size (n=4 video taped tows) during this survey, and the need for greater analysis and understanding of the observer detection curve, catchability was not adjusted for this study and was assumed equal to 1.0.

Scallop Catches

Weathervane scallops were caught in 88% (n=23 tows) of the survey tows (Table 4). Aggregate scallop catch among all tows was 1,636 kg (3,606 lb), or 36% of the weight of all material retained by the dredge. Catches of live scallops per 1.0-nmi tow ranged from 0-165 kg (0-364 lb). Scallop catch dropped dramatically at the edge of the bed (Figure 5). A total of 6,064 individual scallops were caught during the survey (Table 5). Catch abundance ranged from 0-636 scallops per tow; mean catch was 237.9 scallops per tow. Greatest scallop catch occurred in tow 96020, which yielded 10.1% of total scallop catch weight and 11.5% of total survey scallop abundance (Figure 5).

Scallop shells contributed another 12 kg (27 lb). The survey dredge only retained scallop shells from 46% of the stations (n=12).

Size, Age, and Growth

Mean weight of individual scallops ranged from 0.05-0.6 kg (0.13-1.33 lb) within tows; mean weight was 0.26 kg (0.58 lb) among all tows (Table 6). A total of 1,855 shell heights were measured (Table 7; Figure 6). Heights ranged from 16-201 mm (0.6-7.9 in). Weighting of individual tow size distribution by total tow catch abundance indicated the most abundant size class was the 151-160-mm (5.9-6.3-in) size category, representing 14.3% of the sampled population (Figure 6). Shell heights were well represented in the 91-170-mm (3.6-6.7-in) size range, as was the 31-40-mm (1.2-1.6-in) size class that comprised 11.7% of the total population.

Ages from 798 scallops ranged from young-of-the-year age 0+ to age 24 (Table 8; Figure 7). Weighted age composition data indicated 51% of the surveyed population abundance was younger than age 6. Age 4 was the most abundant cohort (15%), although age-1, -3, and -12 scallops also each comprised over 10% of total population abundance. Tow numbers 96004, 96009, and 96010, 96013, and 96025 yielded high catches of age-0 and –1 scallops. However, scallops younger than age 4 were generally found throughout the bed in areas of high scallop abundance.

Size-at-age indicated asymptotic growth for the Kamishak Bay scallop population (Figure 8). The greatest annual growth in height occurred during the first five years of life. Annual height growth rates decreased rapidly to less than 1% per year after about age 13. Annual growth in weight was greatest from about age 2 to age 5 (Figure 9).

The aggregate whole weight of scallops selected randomly for meat recovery was 158 kg (349 lb), and the aggregate meat weight was 13.5 kg (29.80 lb). Mean meat recovery was 8.54%.

Weathervane Scallop Population Estimate

Due to uncertainty about calculating catchability from video observations, the estimate of the weathervane scallop population was based on an assumption of catchability equal to 1.0.

Population estimation also applied a balanced survey design such that the number of sampled stations represented one half of the available stations. Because the survey sampled 26 stations, each 1.0 nmi^2, the total scallop bed was assumed to cover 52 nm^2. Multiplying the bed area by mean scallop catch rate of 0.03kg/m (136.7 lb/nmi) and converting the linear tow distance to an area swept calculation yielded a weathervane scallop population estimate and 95% confidence interval of 2,485 ± 914 metric tons (5.5 ± 2.0 million lb). Based on a mean scallop weight of 0.26 kg (0.58 lb), estimated mean population abundance was 3.2 million scallops.

Tanner Crab

A total of 68 kg (150 lb) of adult Tanner crab was caught from 69% of the stations (n=18) in the 1996 Kamishak Bay survey (Tables 4 and 5). Catches of adult Tanner crab ranged from 0-17 kg (0-30 lb), with the greatest catch from tow 96014. The survey caught 254 adult Tanner crab with a mean weight of 0.3 kg (0.6 lb). Juvenile Tanner crab were caught in 88% (n=23) of the survey stations (Tables 4 and 5). The juvenile crab catch abundance totaled 3,040, but accounted for only 10 kg (22 lb) of the cumulative survey catch weight. Tanner crab were generally caught in the northcentral portion of the survey area (Figure 10).

King Crab

A total of 16 king crab, totaling 21 kg (46 lb), was caught by the survey (Tables 4 and 5), yielding a mean king crab weight of 1.3 kg (2.9 lb). King crab were caught in only 23% (n=6) of the survey stations. Station 96020 yielded the most king crab. King crab were generally caught at stations representing the deeper portion of the surveyed depths in the eastern half of the survey area (Figure 11).

Miscellaneous Fish

Fish species were caught in 85% of the survey tows (n=22), but comprised only 66 lb (30 kg), or less than 1%, of the total survey catch (Tables 4 and 5; Figure 12). Although species-specific contribution to total fish catch was not weighed or enumerated, most of the fish were walleye pollock *Theragra chalcogramma* or flatfish.

DISCUSSION

Under an assumption that survey dredge catchability equals 1.0, the point estimate and 95% confidence interval for weathervane scallops in Kachemak Bay was 2,485 ± 914 metric tons (5.5 ± 2.0 million lb). Estimated population abundance was 3.2 million scallops. Mean meat recovery was 8.54% of whole scallop weight.

Other aspects of the management approach include minimizing the bycatch of Tanner and king crabs. Populations of both of these crab species are insufficient to provide a commercial fishery in the Kamishak Bay District (Bechtol 1998). However, dredge catches of Tanner crab, particularly juveniles, during the scallop survey may be used to supplement data on crab catches from ADF&G bottom trawl surveys. The scallop dredge appears to catch a greater abundance of smaller Tanner crab cohorts than is observed in ADF&G trawl surveys to assess crab (Tables 4 and 5), and the trawl survey has long been recognized as having low selectivity for Tanner crab smaller than 92 mm carapace width (Kimker 1994*b*, 1996; Bechtol 1998). Although the king crab population remains well below historical levels, catches by the scallop dredge also provided an indication that limited king crab recruitment may be occurring (Tables 4 and 5; Figure 11).

We do not understand the processes affecting recruitment, or how various aggregations within the surveyed bed contribute to the reproductive success of the weathervane scallop population in Kamishak Bay. More than half of the Kamishak Bay population was younger than age 6, indicating environmental conditions have been good for reproduction and recruitment in recent years (Figure 7). The time series of commercial age composition data also appears to exhibit continued and steady recruitment for this scallop bed (Figure 13). Commercial fishery age composition data suggests mortality increased rapidly around ages 8-10, as evidenced by declines in cohort abundance at around these ages. However, the relatively strong age-10-13 cohorts observed in the 1996 survey may indicate sampling of a population component not typically fished by the commercial fishery due to rough bottom or aggregations of king or Tanner crabs. The fishery typically avoids areas of significant crab aggregations because of bycatch restrictions that could potentially curtail the fishery (Kimker 1994*a*). In addition, the age-4-6 scallop cohorts were not as dominant as in the commercial fisheries, probably due to the influence of younger age classes on the overall age composition for the survey.

The Kachemak Bay fishery for weathervane scallops is annually managed for a guideline harvest range of 53-106 metric tons (10,000-20,000 lb) of meats. The fishery appears to be sustainable under this constant harvest strategy, although fishing effort has not occurred every year since the fishery's inception in 1983 (Kimker 1994*a*). Management for the upper end of the range in the 1996 fishery would represent a harvest rate of 4.3% of the standing stock.

Under the empirical approach of Hoenig (1983), natural mortality rates for the Kamishak Bay population can be approximated as M=0.19, corresponding to an annual mortality rate of 17%, for the maximum observed age of 24 years. This agrees well with estimates of 4-22% obtained by Kruse (1994) for *P. caurinus* and the median estimate of 15% reported by Kruse (1994) using

a maximum scallop age of 28 years as reported by Hennick (1973). Under an approach that fishing mortality should not exceed natural mortality, fishery management in 1996 for the upper end of the guideline harvest range in Kamishak Bay should present a conservative approach that continues to provide for long-term sustainability to the scallop population.

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Table 1. Weathervane scallop harvests from the Kamishak District, Cook Inlet Management District during 1983 to 1995.

Year	Number of vessels	Catch (lb) of shucked meats	lb/hour
1983	1	2,346	21.5
1984	3	6,305	25.4
1985	1[a]	11,810	39.5
1986	3	15,364	36.2
1987	2[b,c]	360	15.1
1988		No Effort	
1989		No Effort	
1990		No Effort	
1991		No Effort	
1992		No Effort	
1993	3	20,115	38.1
1994	4	20,431	44.6
1995		CLOSED	

[a]Season and harvest guideline set by regulation.
[b]Season closed by E.O. on August 21,1987, one week after opening , due to low CPUE.
[c]Does not include an Outer District harvest of 1,128 lb of shucked meats by 1 vessel.

Table 2. Set data for dredge tows made during the 1996 Kamishak Bay scallop survey.

Tow	Date	Time	Start Location		Course	Speed	Duration	Scope	Tow Depth (fathom)	
			Latitude (N)	Longitude (W)	Made Good	(kt)	(min)	(fathom)	Minimum	Maximum
96001	7-July	10:23	59°25.57'	153°10.81'	289°	3.5	22	75	20	22
96002	7-July	11:45	59°25.36'	153°06.93'	300°	4.0	18	100	21	23
96003	7-July	12:45	59°25.38'	153°03.01'	295°	3.8	17	125	22	24
96004	7-July	13:45	59°24.51'	153°00.81'	290°	4.0	16	125	24	25
96005	7-July	14:26	59°24.54'	153°04.76'	308°	4.0	23	125	22	23
96006	7-July	15:21	59°25.40'	153°10.60'	124°	4.0	17	100	22	21
96007	7-July	16:04	59°24.35'	153°11.85'	123°	4.0	17	100	23	21
96008	8-July	10:01	59°19.63'	153°10.81'	307°	4.0	16	115	28	28
96009	8-July	10:49	59°20.67'	153°08.71'	288°	4.0	16	115	27	27
96010	8-July	11:37	59°22.44'	153°04.54'	294°	4.0	17	115	25	27
96011	8-July	12:30	59°22.43'	153°00.60'	300°	4.0	17	120	27	29
96012	8-July	13:11	59°23.45'	152°58.54'	284°	4.0	18	115	27	28
96013	8-July	13:58	59°23.47'	153°02.52'	293°	4.0	17	100	24	26
96014	8-July	14:40	59°23.47'	153°06.76'	291°	4.0	18	100	22	24
96015	8-July	15:25	59°22.43'	153°08.56'	300°	3.8	19	100	23	24
96016	8-July		Dredge inverted during initial tow of station; tow repeated.							
" "	8-July	17:07	59°23.48'	153°13.71'	136°	4.0	15	100	22	25
96017	8-July	17:35	59°22.42'	153°12.51'	118°	3.8	18	100	24	25
96018	9-July	09:54	59°18.56'	153°12.73'	302°	4.1	16	120	27	27
96019	9-July	10:57	59°21.63'	153°06.48'	290°	4.0	17	115	25	27
96020	9-July	11:53	59°21.52'	153°02.48'	290°	4.0	20	120	27	29
96021	9-July	12:46	59°21.54'	152°58.53'	295°	4.0	17	125	29	31
96022	9-July	13:04	59°20.43'	153°00.56'	295°	4.0	18	125	29	31
96023	9-July	14:17	59°20.48'	153°04.51'	295°	4.0	16	115	26	28
96024	9-July	15:17	59°19.47'	152°58.71'	300°	4.0	18	125	31	32
96025	9-July	15:57	59°19.5'	153°02.68'	295°	4.0	17	125	28	30
96026	9-July	16:38	59°19.45'	153°06.64'	295°	4.0	17	115	27	28

Table 3. Comparisons of scallop counts between observations of underwater videotapes and survey dredge catches, Kamishak Bay, 1996.

Video Observer 1

Tow	Station	Left-Center	Right-Center	Average	Expanded
96008	B8	26	33	29.5	118
96011	G5	161	189	175.0	700
96019	D6	221	143	182.0	728
96025	F8	139	173	156.0	624

Video Observer 2

Tow	Station	Left-Center	Right-Center	Average	Expanded
96008	B8				
96011	G5	194	202	198.0	792
96019	D6	197	151	174.0	696
96025	F8	124	167	145.5	582

Video Observation compared to Dredge Catches

		Observed			Dredge
Tow	Station	Average	Variance	Expanded	Catch
96008	B8	29.5	24.5	118	209
96011	G5	186.5	317.7	746	411
96016	A5	Dredge inverted, camera not used on replicate tow.			
96019	D6	178.0	1,388.0	712	452
96023	E7	Video tape ran out prior to completion of tow.			
96025	F8	150.8	537.6	603	523

Note – See text for description of methods.

Table 4. Catch weight composition during the 1996 Kamishak Bay scallop survey.

Tow Number	Pounds per nautical mile tow: Scallops (whole)	Scallop shells	Tanner Crab	Juvenile Tanner	King Crab	Misc. Fish	Debris	Total Catch
96001	46	0	6	1	0	1	172	226
96002	18	0	16	1	0	1	185	221
96003	20	0	0	1	0	1	178	200
96004	58	0	0	0	0	1	46	105
96005	92	4	4	1	6	2	84	193
96006	82	1	14	3	0	3	106	209
96007	102	0	5	1	0	2	588	698
96008	228	1	2	2	0	3	672	908
96009	266	2	4	1	0	1	264	538
96010	224	4	6	1	3	0	82	320
96011	124	0	1	2	0	10	30	167
96012	6	1	0	0	0	5	26	38
96013	268	2	4	2	0	1	62	339
96014	280	2	30	1	1	1	86	401
96015	222	0	19	1	0	1	218	461
96016	0	0	2	1	0	1	1,349	1,353
96017	0	0	0	1	0	1	1,212	1,214
96018	1	0	0	0	0	0	406	407
96019	282	1	18	1	0	6	68	376
96020	364	1	4	1	24	1	32	427
96021	1	0	1	1	8	0	18	29
96022	236	0	0	1	0	0	20	257
96023	318	0	10	1	0	12	44	385
96024	0	0	0	1	0	1	48	50
96025	234	4	0	1	4	10	68	321
96026	134	4	4	1	0	1	48	192
Total	3,606	27	150	22	46	66	6,112	10,029
Average	138.7	1.0	5.8	0.8	1.8	2.5	235.1	385.7

Table 5. Catch abundance of commercially important species caught during the 1996 Kamishak Bay scallop survey.

Tow Number	Animals per nautical mile tow			
	Scallops	Adult Tanner Crab	Juvenile Tanner Crab	King Crab
96001	40	8	292	0
96002	22	36	353	0
96003	15	0	118	0
96004	60	0	0	0
96005	189	8	197	2
96006	79	21	265	0
96007	97	32	81	0
96008	209	5	266	0
96009	284	10	102	0
96010	525	6	128	2
96011	411	1	210	0
96012	12	0	0	0
96013	509	5	181	0
96014	303	48	103	1
96015	240	40	135	0
96016	0	5	68	0
96017	0	0	45	0
96018	2	0	0	0
96019	452	16	127	0
96020	709	3	65	9
96021	8	0	50	1
96022	392	0	68	0
96023	636	8	48	0
96024	0	0	28	0
96025	523	0	38	1
96026	347	2	72	0
Total	6,064	254	3,040	16
Average	233.2	9.8	116.9	0.6

Table 6. Weathervane scallop weight, abundance, and mean weight by tow during the 1996 Kamishak Bay survey.

Tow	Scallop Weight (lb)	% of Total	Scallop Abundance Number	% of Total	Mean Weight (lb)
96001	46	1.3%	40	0.7%	1.15
96002	18	0.5%	22	0.4%	0.82
96003	20	0.6%	15	0.2%	1.33
96004	58	1.6%	60	1.0%	0.97
96005	92	2.6%	189	3.1%	0.49
96006	82	2.3%	79	1.3%	1.04
96007	102	2.8%	97	1.6%	1.05
96008	228	6.3%	209	3.4%	1.09
96009	266	7.4%	284	4.7%	0.94
96010	224	6.2%	525	8.7%	0.43
96011	124	3.4%	411	6.8%	0.30
96012	6	0.2%	12	0.2%	0.50
96013	268	7.4%	509	8.4%	0.53
96014	280	7.8%	303	5.0%	0.92
96015	222	6.2%	240	4.0%	0.93
96016	0	0.0%	0	0.0%	-
96017	0	0.0%	0	0.0%	-
96018	1	0.0%	2	0.0%	0.50
96019	282	7.8%	452	7.5%	0.62
96020	364	10.1%	709	11.7%	0.51
96021	1	0.0%	8	0.1%	0.13
96022	236	6.5%	392	6.5%	0.60
96023	318	8.8%	636	10.5%	0.50
96024	0	0.0%	0	0.0%	-
96025	234	6.5%	523	8.6%	0.45
96026	134	3.7%	347	5.7%	0.39
Total	3,606	100.0%	6,064	100.0%	-
Average	138.7		233.2		0.59

Table 7. Shell height frequency distribution of weathervane scallops captured during a dredge survey in Kamishak Bay, 1996.

	Shell Height (mm)																			Total	Sample
Tow	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	n	n
96001	0	0	0	0	0	0	0	0	1	2	7	1	3	3	15	6	2	0	0	40	40
96002	0	0	0	0	0	0	0	0	3	0	2	1	2	8	6	0	0	0	0	22	22
96003	0	0	0	0	0	0	0	0	0	0	2	2	0	1	5	4	0	0	1	15	15
96004	0	7	85	23	0	1	0	1	7	8	7	4	3	8	16	12	0	0	0	182	182
96005	0	12	20	0	6	4	0	8	32	8	32	16	2	9.9	28	12	0	0	0	189	95
96006	0	0	0	0	0	0	0	0	4	1	3	6	4	15	28	15	2	0	0	78	78
96007	0	0	1	0	0	0	0	2	1	1	3	6	7	21	32	19	3	0	0	96	96
96008	0	0	2.1	0	0	0	0	2.1	4.2	4.2	10	25	15	38	50	54	4.2	0	0	209	100
96009	0	0	8.3	0	0	0	2.8	2.8	22	11	14	33	28	44	66	41	11	0	0	284	103
96010	5.3	16	74	5.3	11	32	11	11	137	68	79	11	5.3	16	37	11	0	0	0	525	100
96011	0	4.1	99	33	0	12	16	12	53	45	66	37	4.1	0	21	8.2	0	0	0	411	100
96012	0	0	3	5	0	0	0	0	1	0	0	0	2	0	1	0	1	0	0	13	13
96013	0	5.1	107	15	10	15	10	10	92	36	56	20	15	46	41	31	0	0	0	509	100
96014	3	0	21	3	3	9.1	0	3	15	21	15	24	9.1	61	67	42	6.1	0	0	303	100
96015	2.4	0	2.4	2.4	2.4	0	0	4.8	4.8	14	24	7.1	9.5	43	71	43	9.5	0	0	240	101
96016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96018	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2	2
96019	9	14	81	4.5	27	4.5	4.5	14	14	32	18	32	4.5	81	77	36	0	0	0	452	100
96020	0	0	50	0	7.1	28	14	14	121	156	85	64	21	50	57	35	7.1	0	0	709	100
96021	0	1	1	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8
96022	0	0	12	20	3.9	16	27	3.9	24	59	47	63	35	7.8	24	35	16	0	0	392	100
96023	0	6.4	108	25	0	6.4	19	6.4	95	76	13	13	38	121	95	13	0	0	0	636	100
96024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96025	0	0	21	52	0	16	10	0	26	68	37	89	26	78	78	21	0	0	0	523	100
96026	0	0	28	38	0	10	3.5	14	10	45	6.9	3.5	42	66	73	6.9	0	0	0	347	100
Total	20	65	722	232	71	154	119	108	667	656	526	458	275	717	887	446	62	0	1	6,185	1,855
Percent	0.3%	1.0%	11.7%	3.7%	1.2%	2.5%	1.9%	1.8%	10.8%	10.6%	8.5%	7.4%	4.5%	11.6%	14.3%	7.2%	1.0%	0.0%	0.0%	100.0%	

Table 8. Age composition of weathervane scallops caught in a survey of Kamishak Bay, 1996.

	Age Class (years)																								
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	24	Total	Sample
Tow	Catch Abundance of Scallops																							
96001	0	0	0	1	1	5	1	1	0	3	0	5	4	11	3	1	3	0	0	0	0	0	40	30
96002	0	0	0	0	3	3	1	1	0	2	4	5	2	1	0	0	0	0	0	0	0	0	22	22
96003	0	17	0	0	2	0	2	0	0	1	1	2	1	3	2	0	0	0	0	0	0	1	32	32
96004	0	115	1	3	1	2	1	0	0	1	2	6	9	6	3	0	1	0	0	1	0	0	152	152
96005	0	0	0	8	55	8	8	0	0	8	16	16	16	24	16	8	0	0	8	0	0	0	189	24
96006	0	0	0	0	10	3	3	3	8	16	3	5	13	5	0	5	3	3	0	0	0	0	78	30
96007	0	0	0	0	3	3	10	7	10	7	0	13	17	13	7	3	0	3	0	0	0	0	97	29
96008	0	0	14	14	14	14	7	7	21	0	0	14	42	14	21	21	0	7	0	0	0	0	209	30
96009	0	100	11	17	22	28	17	11	0	22	17	0	28	6	6	0	0	0	0	0	0	0	284	51
96010	0	164	66	98	88	11	0	0	0	0	0	11	44	22	0	11	0	11	0	0	0	0	525	48
96011	0	0	14	96	219	14	0	0	14	0	0	27	14	14	0	0	0	0	0	0	0	0	411	30
96012	0	4	0	2	2	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	12	6
96013	104	39	0	131	52	13	13	13	13	0	39	13	52	13	0	13	0	0	0	0	0	0	509	39
96014	0	0	0	40	30	40	0	0	0	30	30	0	40	61	20	0	10	0	0	0	0	0	303	30
96015	8	0	0	15	46	15	8	8	0	8	8	15	31	39	8	0	0	15	0	8	8	0	240	31
96016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96018	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2
96019	0	0	16	31	62	16	0	0	0	78	47	62	62	62	0	0	0	16	0	0	0	0	452	29
96020	0	0	0	165	142	47	0	24	47	0	47	95	95	47	0	0	0	0	0	0	0	0	709	30
96021	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8
96022	0	0	0	13	105	65	0	13	0	0	39	13	26	52	39	0	0	0	13	13	0	0	392	30
96023	0	0	42	127	21	21	0	21	21	0	21	106	127	42	42	0	21	0	21	0	0	0	636	30
96024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
96025	0	209	29	48	67	19	0	10	29	10	19	29	10	38	0	0	0	0	10	0	0	0	523	55
96026	0	0	35	35	0	12	0	12	35	46	23	35	58	35	12	12	0	0	0	0	0	0	347	30
Total	112	657	227	846	948	341	70	129	197	231	316	473	692	507	178	74	38	55	52	22	8	1	6,172	798

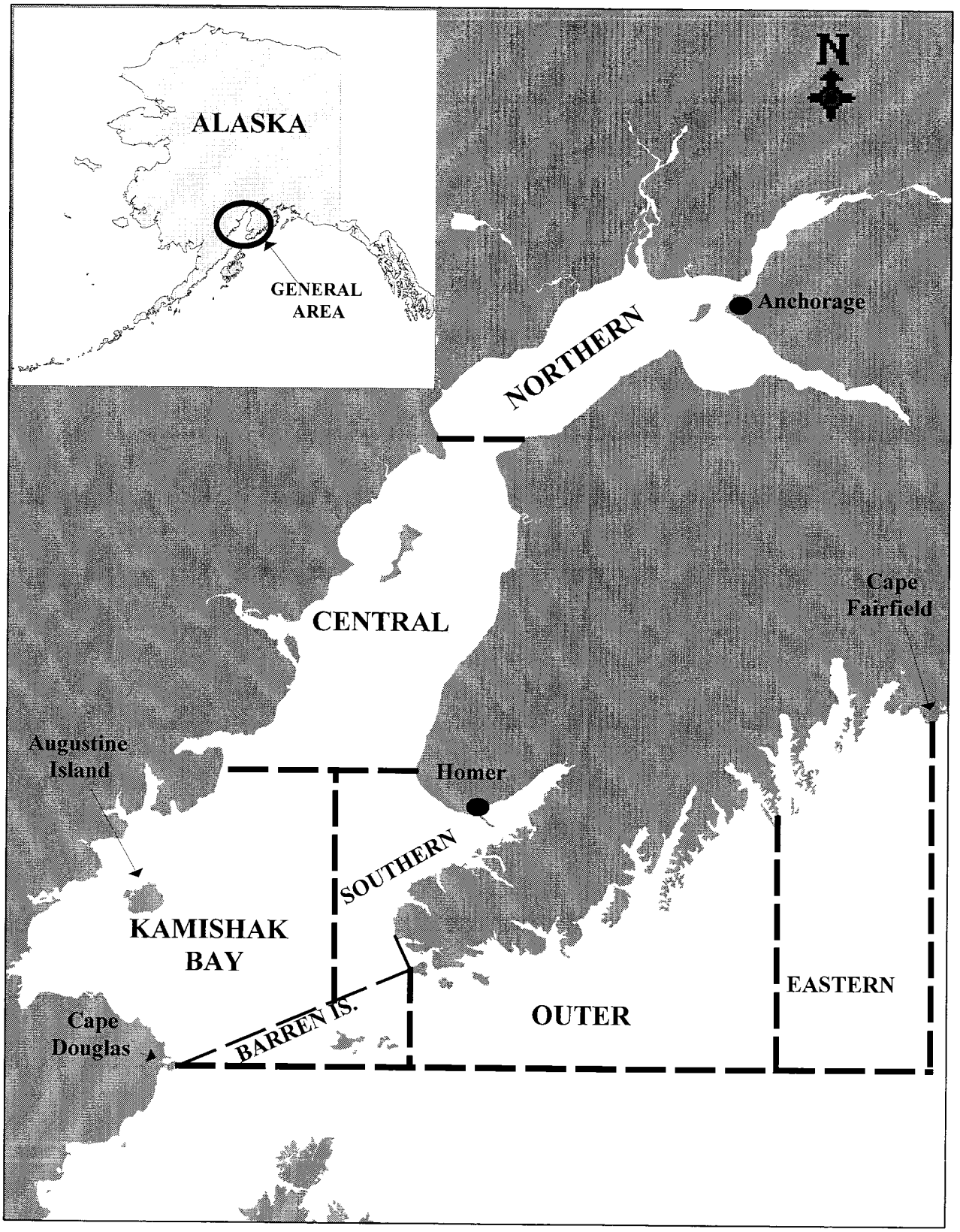

Figure 1. General study area for an assessment of weathervane scallops in Kamishak Bay, 1996.

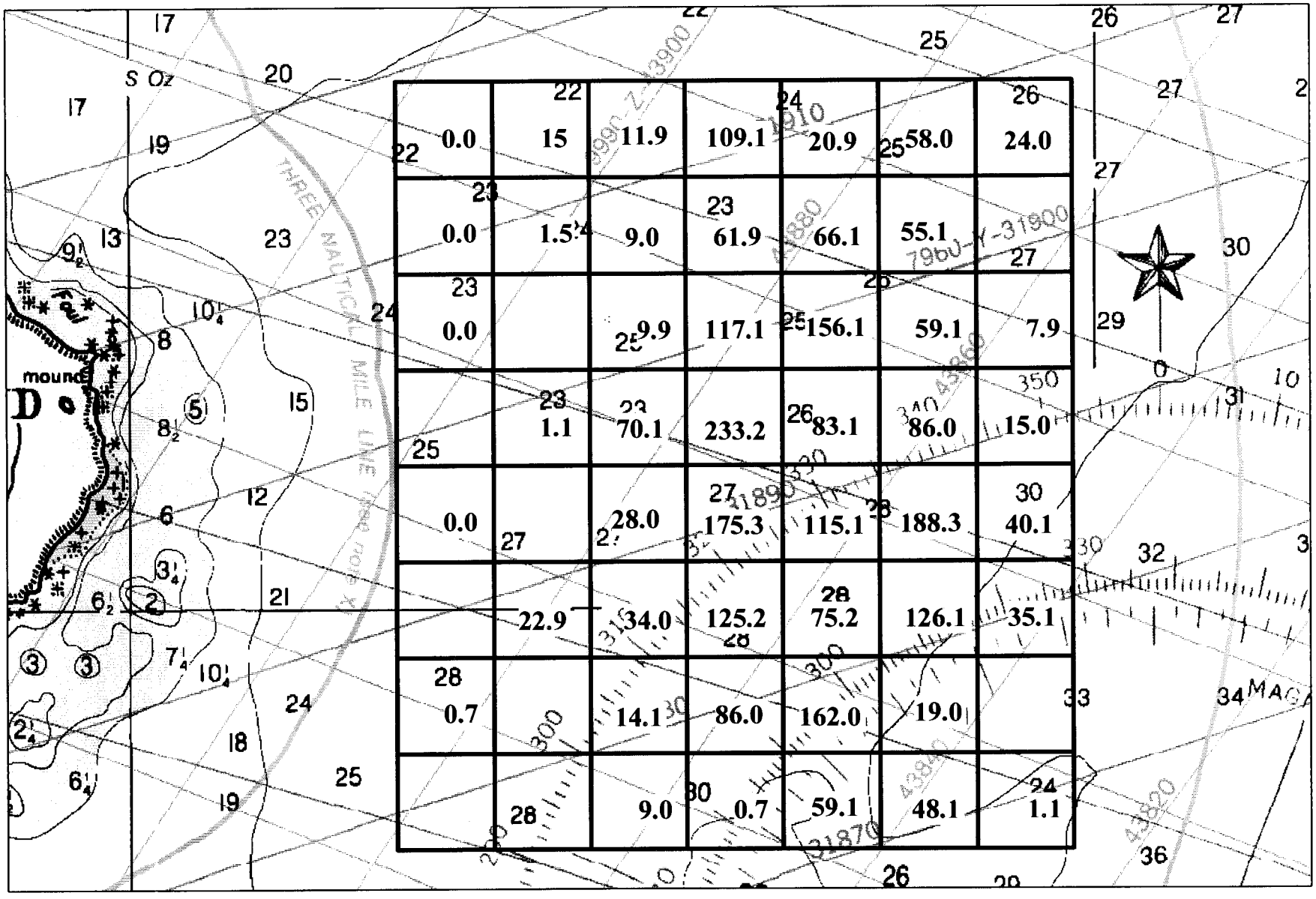

Figure 2. Weathervane scallop survey catches (lb/tow) in a 1984 dredge survey of Kamishak Bay, Alaska.

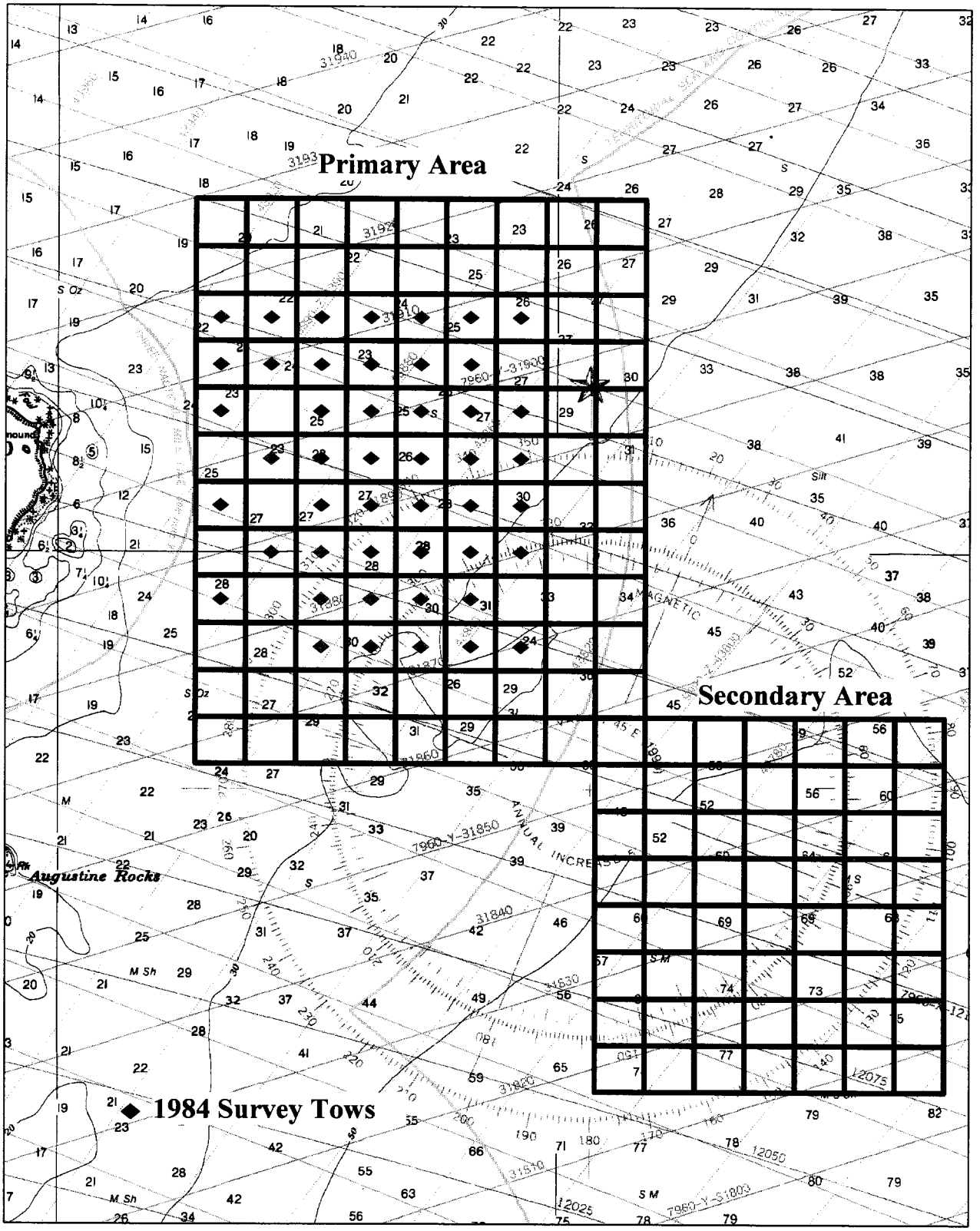

Figure 3. Kamishak Bay study area showing primary and secondary survey grids proposed for the 1996 scallop survey and the 1984 survey tow locations.

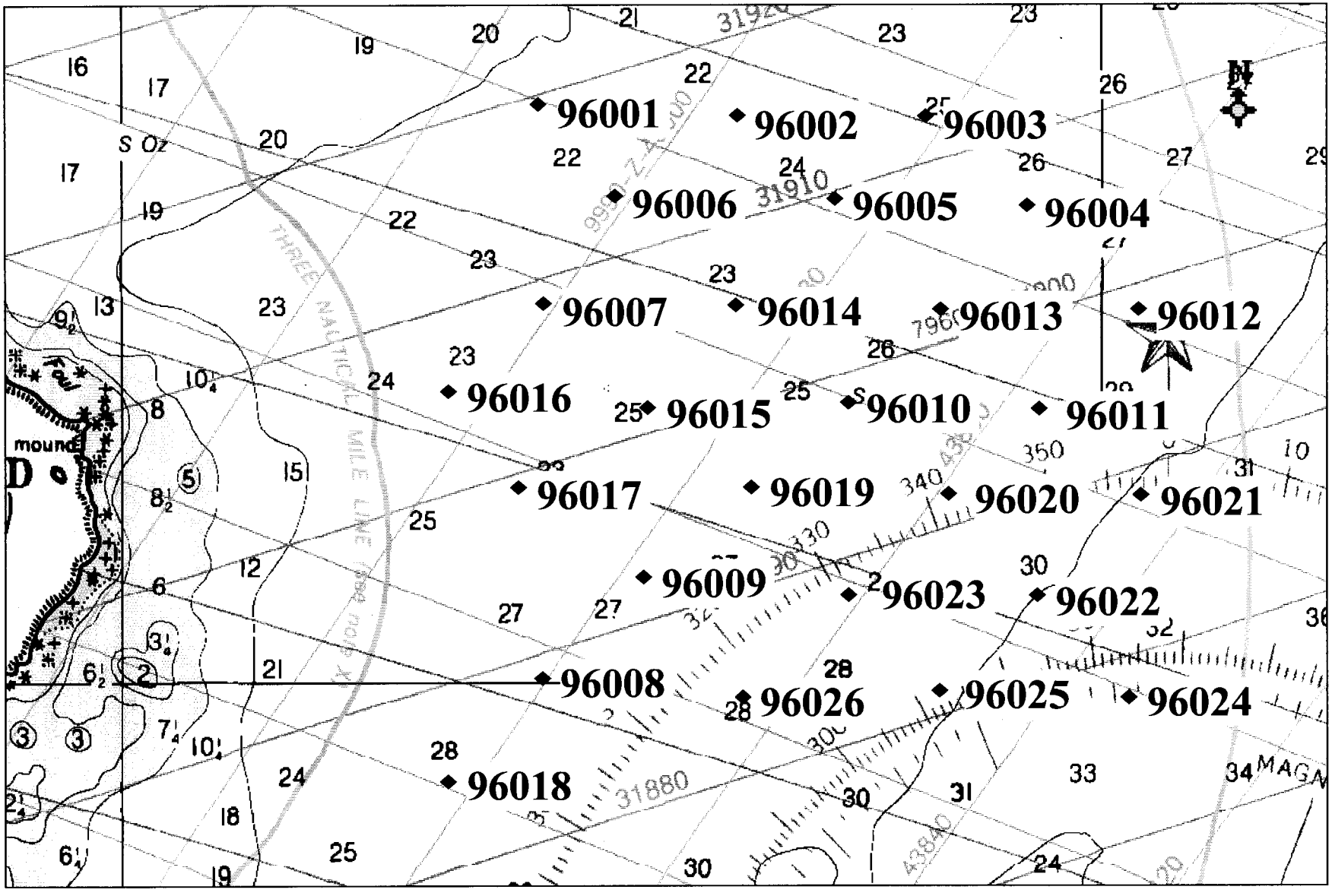

Figure 4. Midpoints of 23 successful tows made during a dredge survey for weathervane scallops in Kamishak Bay, 1996.

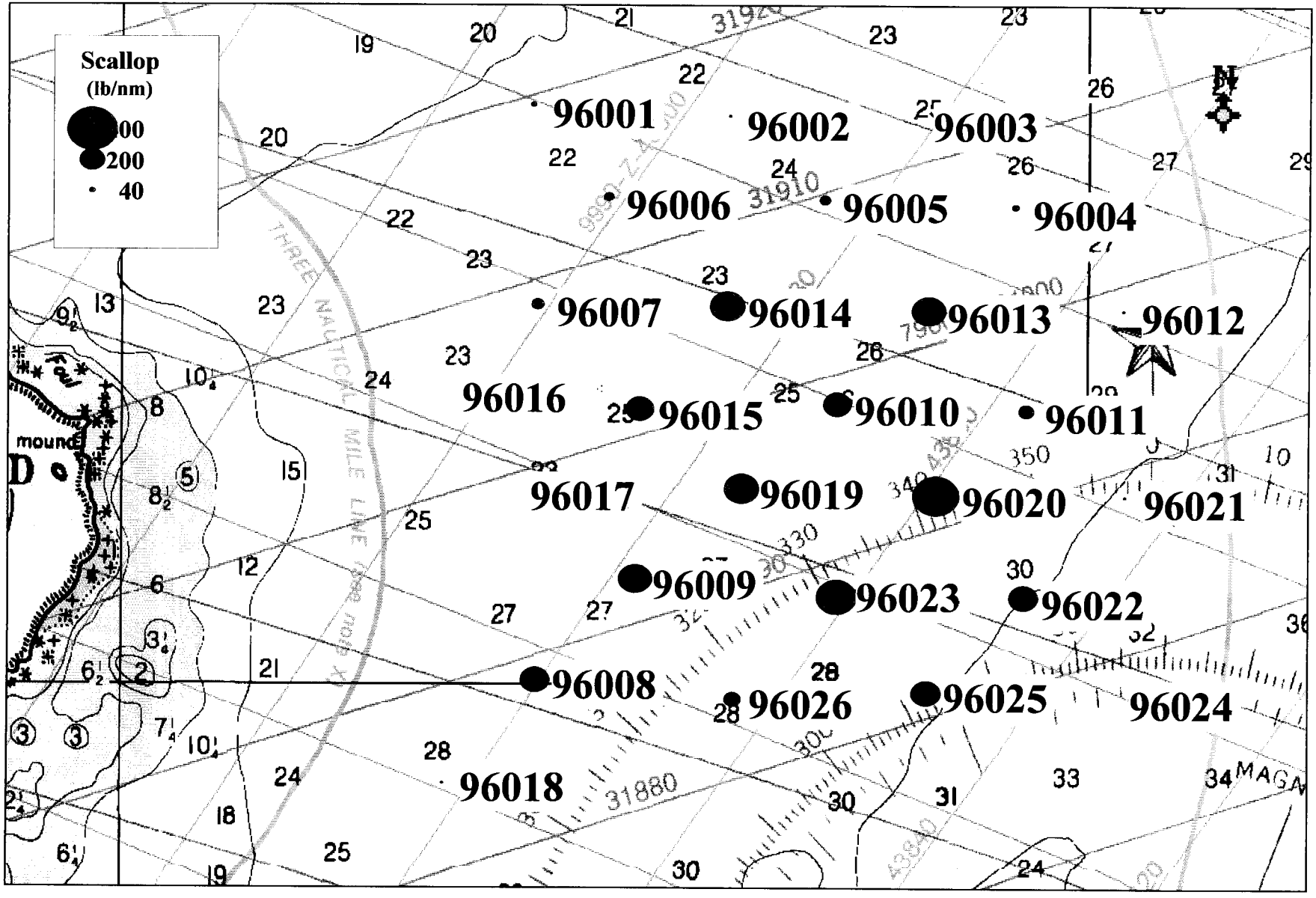

Figure 5. Distribution of weathervane scallop catches during a dredge survey of Kamishak Bay, 1996.

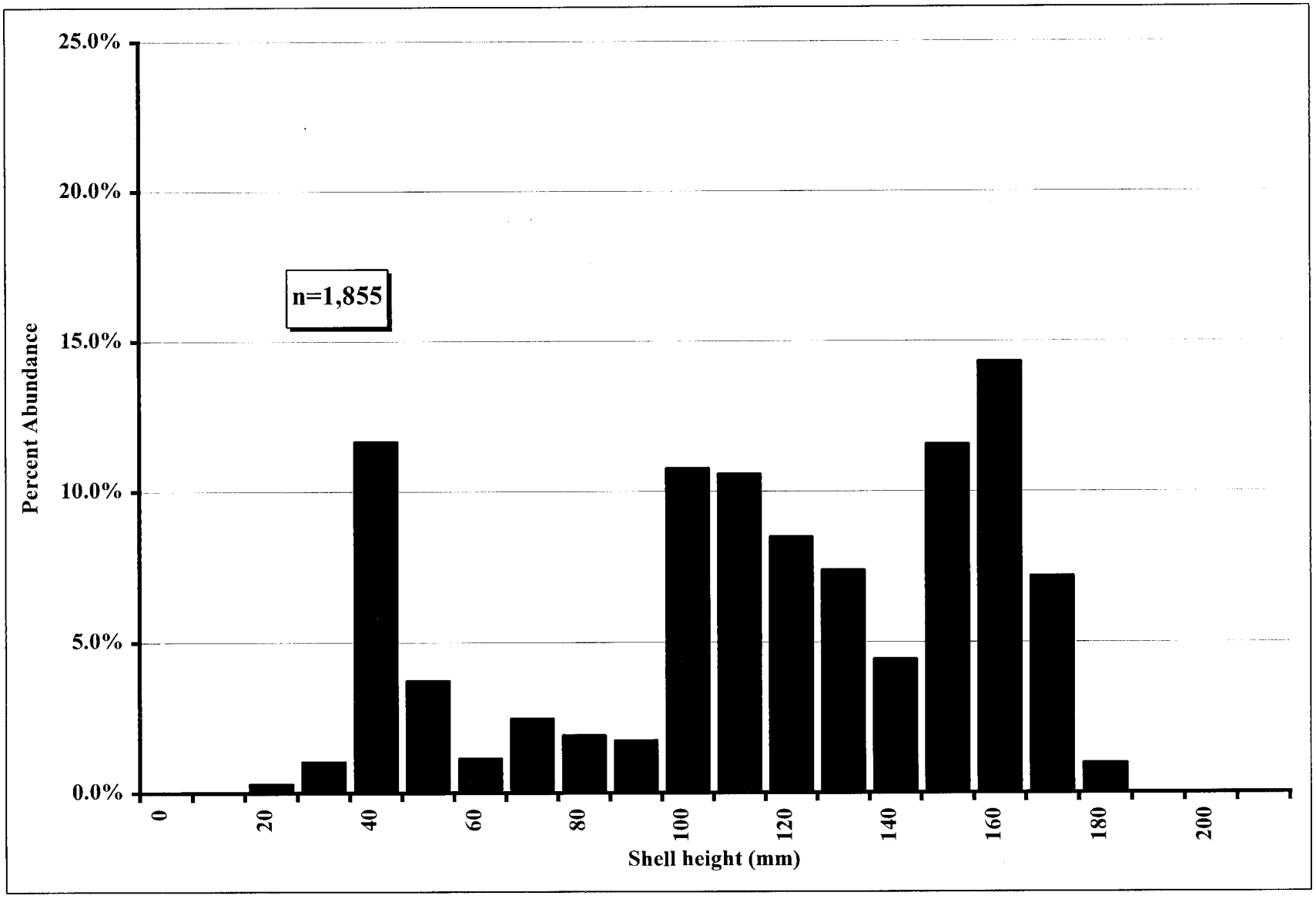

Figure 6. Shell height distribution from weathervane scallops caught during a dredge survey of Kamishak Bay, 1996.

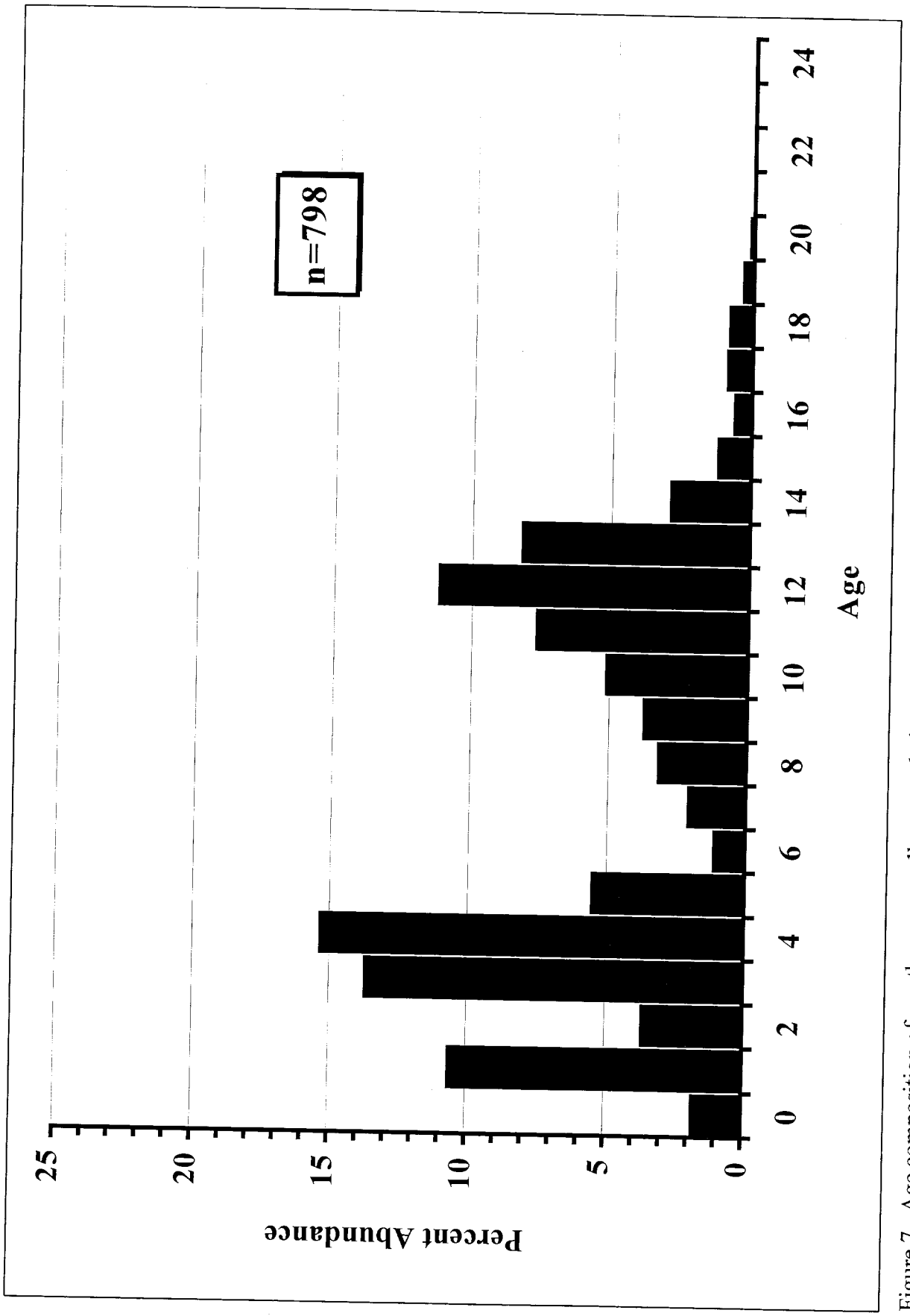

Figure 7. Age composition of weathervane scallops caught in a dredge survey of Kamishak Bay, 1996.

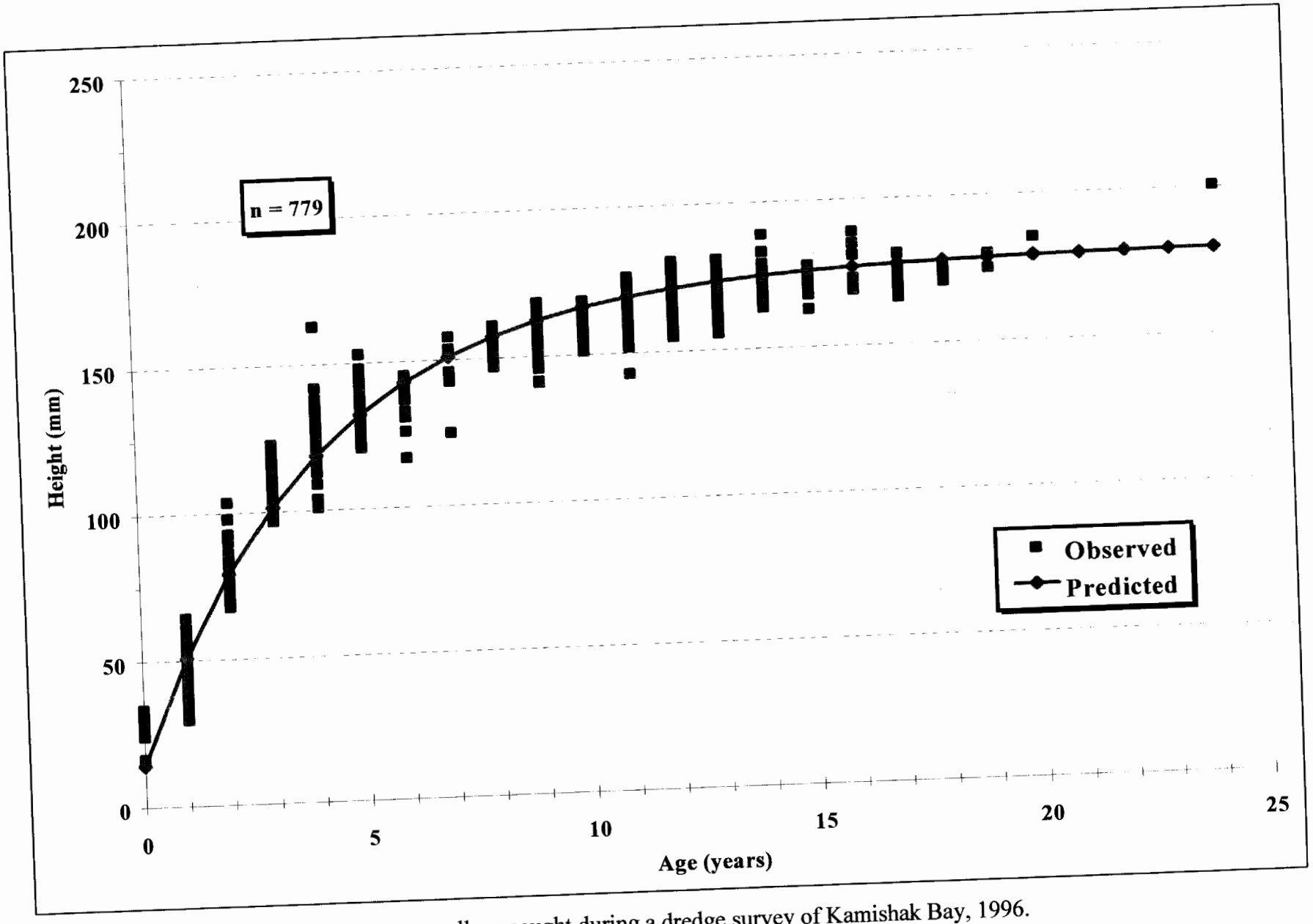

Figure 8. Height-at-age for weathervane scallops caught during a dredge survey of Kamishak Bay, 1996.

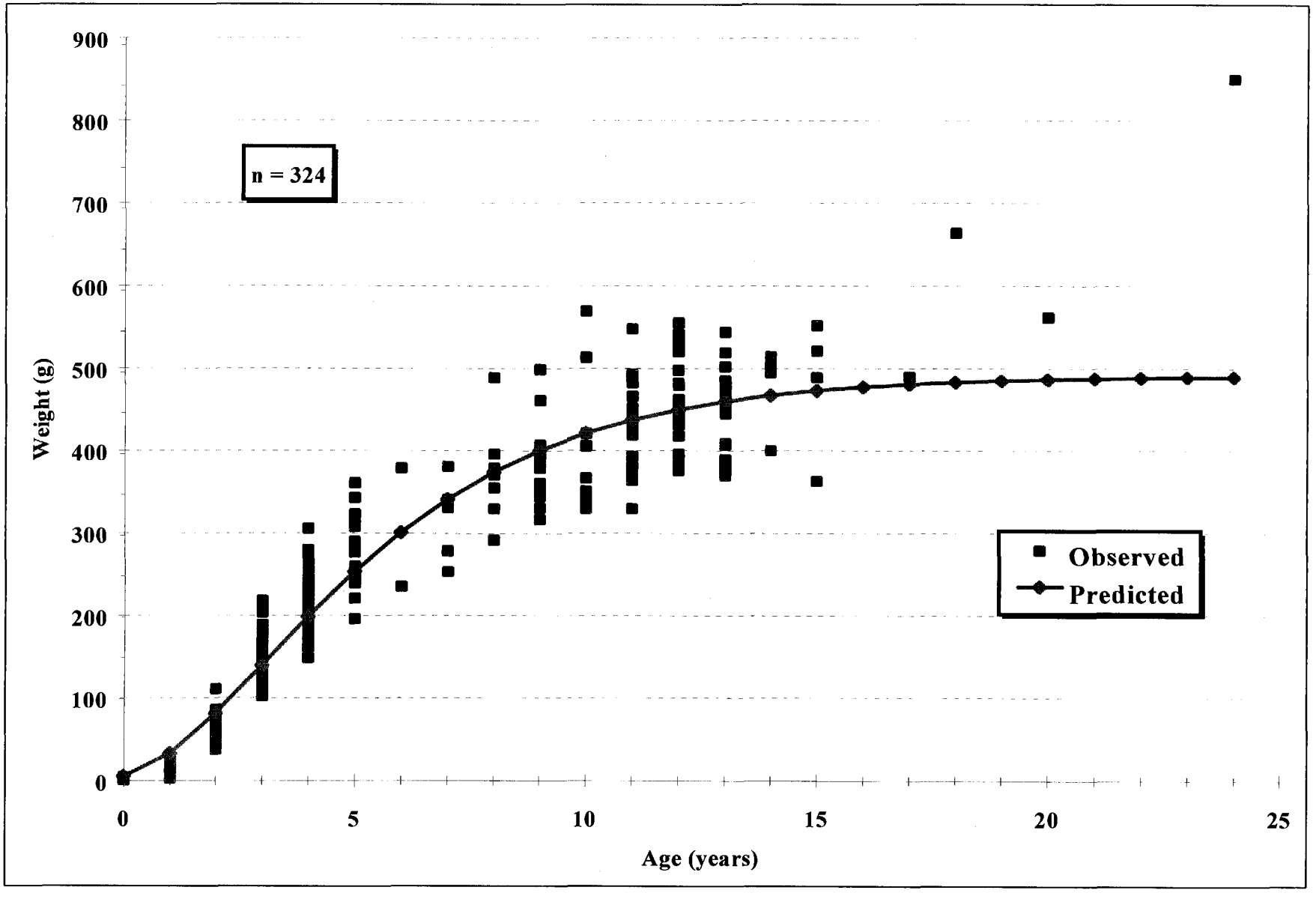

Figure 9. Weight-at-age for weathervane scallops caught during a dredge survey of Kamishak Bay, 1996.

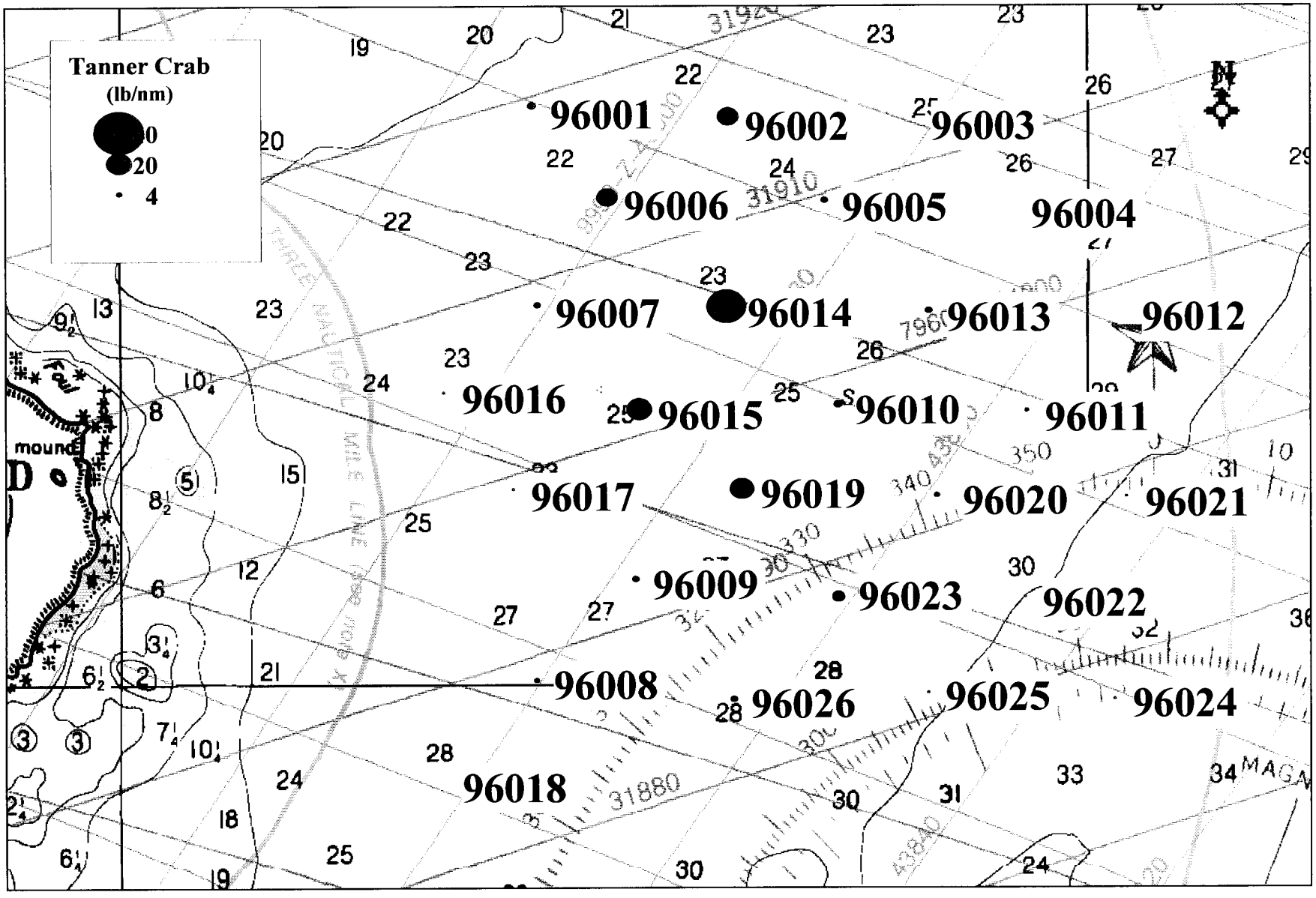

Figure 10. Distribution of Tanner crab catches during a scallop dredge survey in Kamishak Bay, 1996.

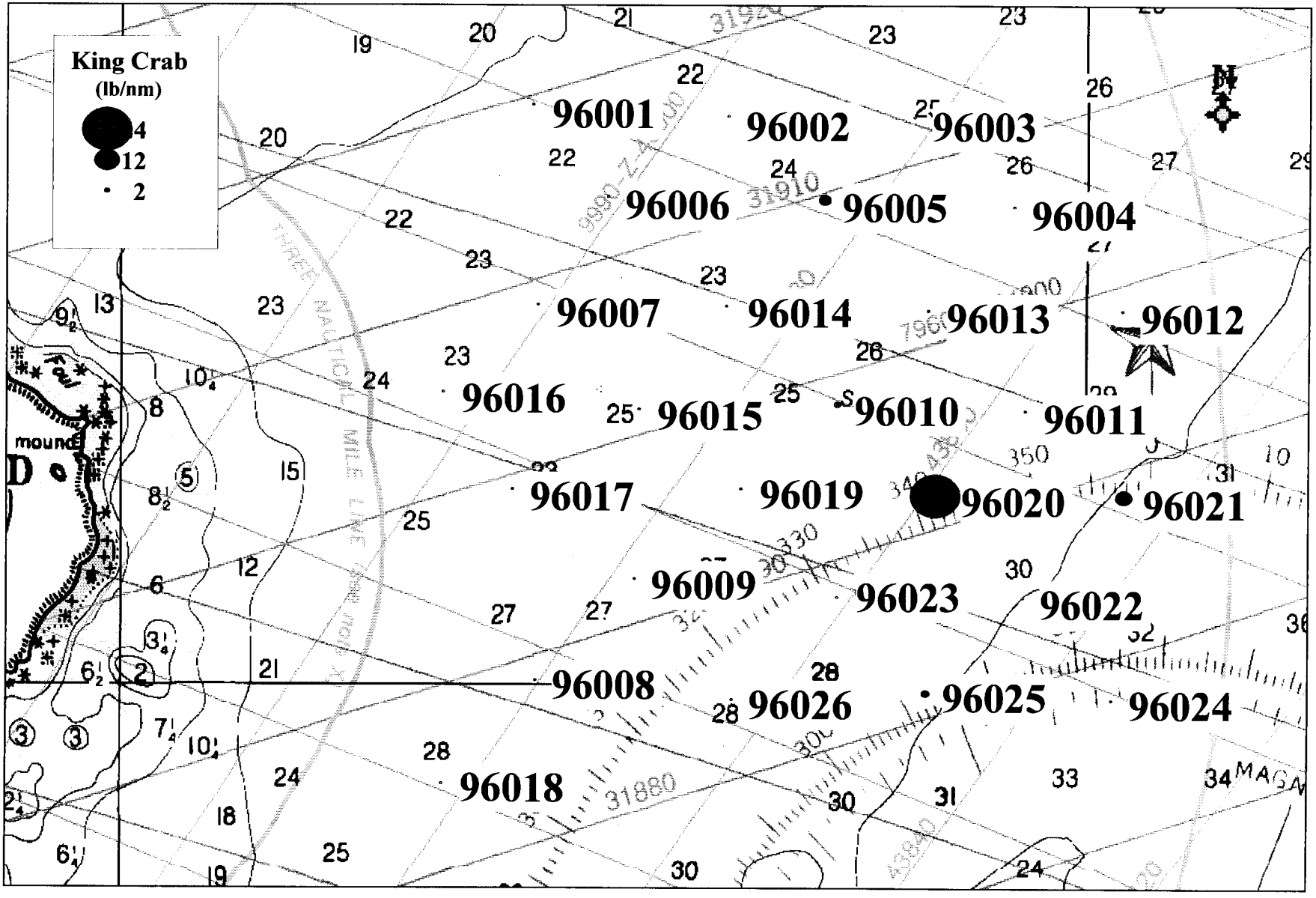

Figure 11. Distribution of king crab catches during a scallop dredge survey in Kamishak Bay, 1996.

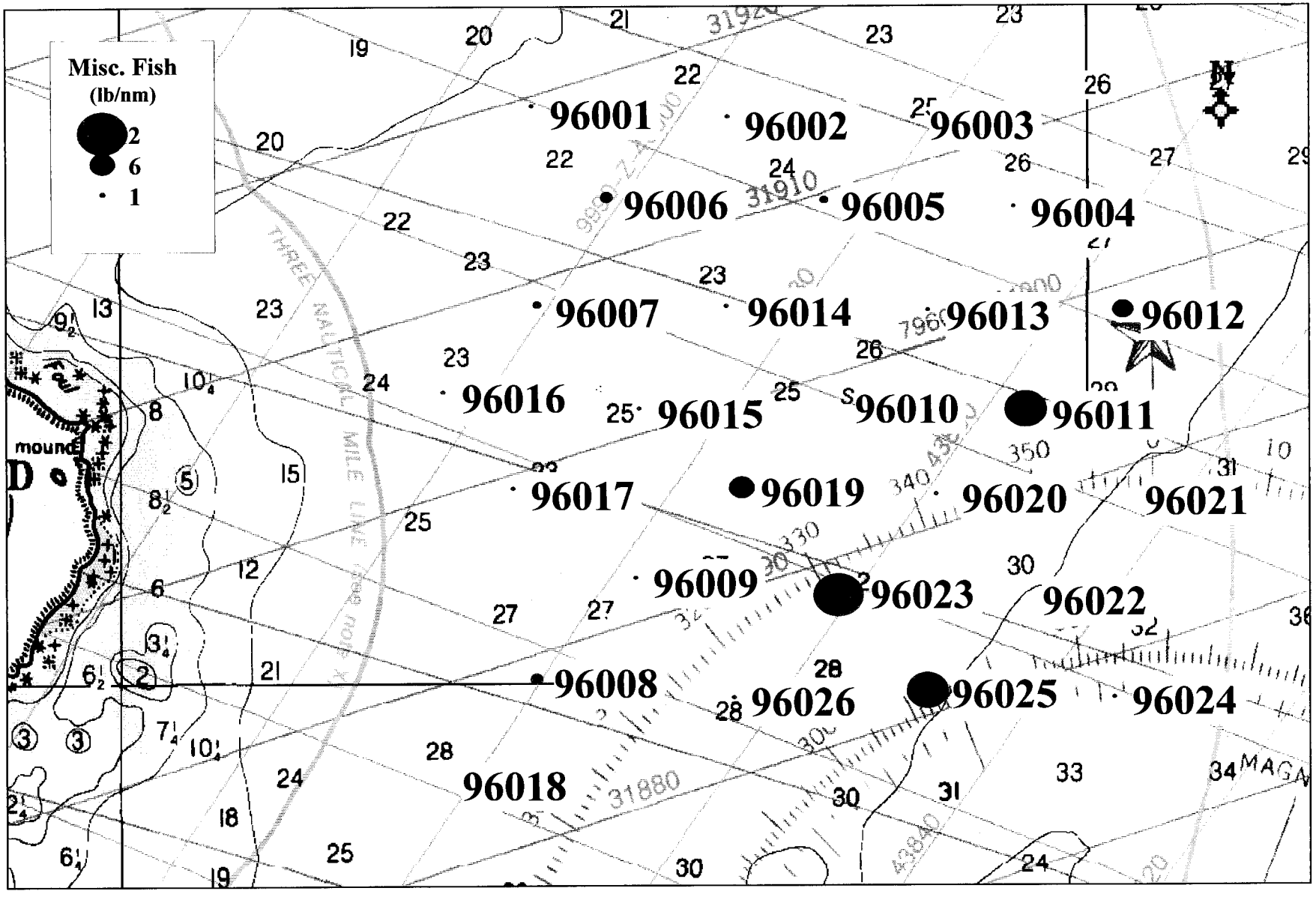

Figure 12. Distribution of fish catches during a scallop dredge survey in Kamishak Bay, 1996.

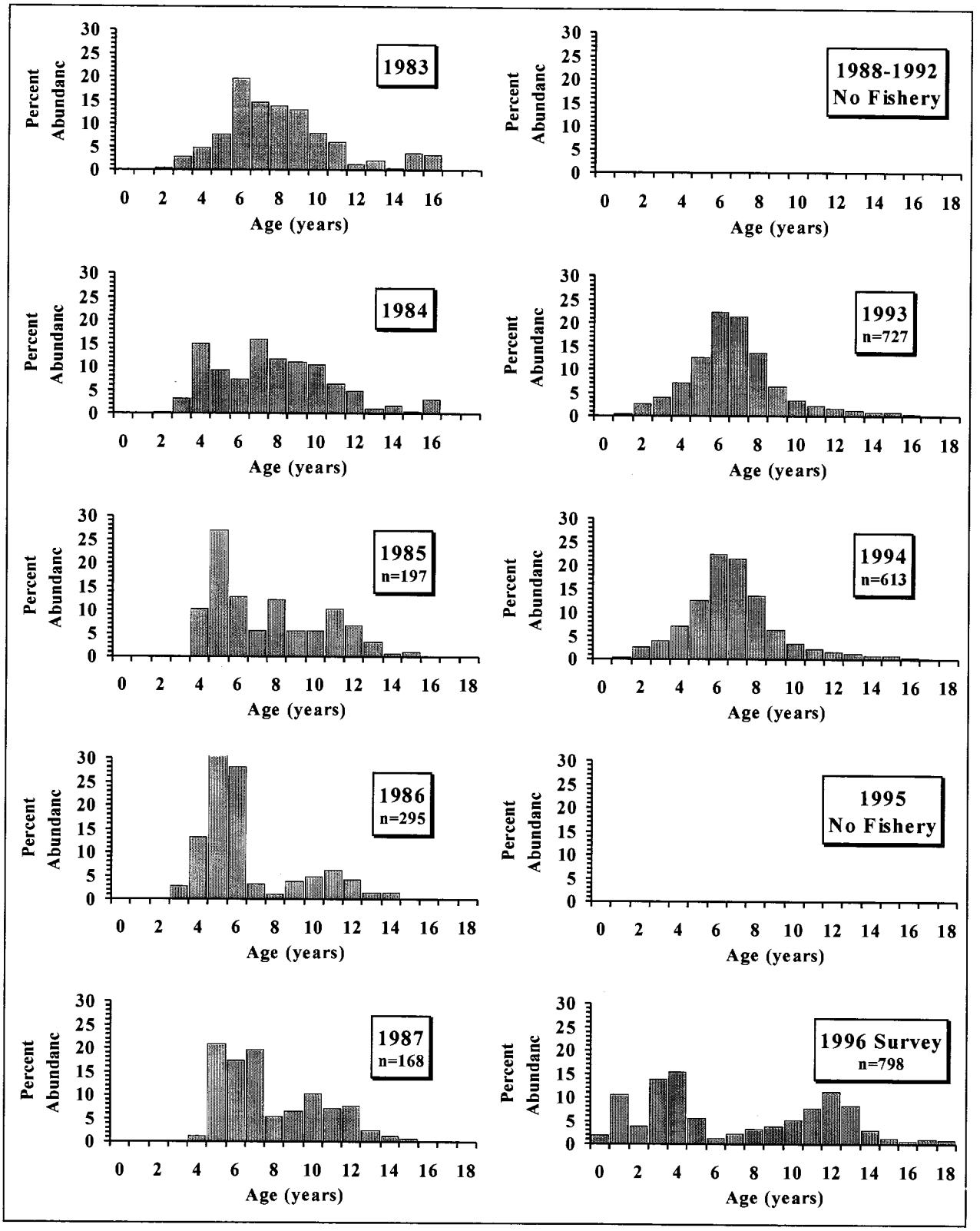

Figure 13. Age composition of weathervane scallops caught in Kamishak Bay by commercial fisheries during 1985-1995 and by a department survey in 1996.

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