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## Evaluation of Haul Weight Estimation Procedures Used by At-sea Observers in Pollock Fisheries off Alaska

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# Evaluation of haul weight estimation procedures used by at-sea observers in pollock fisheries off Alaska

by

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## SUMMARY

Haul weight estimation procedures used by North Pacific groundfish observers were evaluated during a research charter of the factory trawler (FT) *American Triumph* during the 1996 walleye pollock B season and the 1997 A season in the Bering Sea. A motion-compensated belt-conveyor scale, or "flow" scale, was tested for precision and bias using known weights of fish. Flow scale weights were sufficiently accurate to evaluate the volumetric methods of haul weight estimation currently used by observers. In addition, flow scale weights were used to obtain new estimates of pollock density to convert fish volume to weight. Volumetric methods evaluated during the research charter included codend volume measurements by observers, bin volume measurements by observers, and bin volume measurements by electronic bin sensors. Density was estimated by three methods: first, by comparing codend or bin volumetric estimates to their corresponding flow scale weights; second, using a specially designed density sampler; and third, using standard observer sampling baskets. Densities based on flow scale weights and bin volumes (*in situ* densities) were used to evaluate the accuracy of densities estimated with sampling baskets and the density sampler.

### Findings

- Based on our experience during the research charter, the flow scale was reliable, trouble-free, and easy to operate in a seafood processing factory on a fishing vessel. Based on our observations, the flow scale had the highest precision of any haul weight estimation method *when operated correctly*. This study evaluated the performance of a single scale on a 87 m factory trawler; scale performance may depend on scale manufacturer and vessel size.

- The flow scale performed within the error limits of ±3% of true weight in daily materials tests where a known weight of fish was passed across the scale. However, a slight, but consistent, positive bias of +1% was detected during each season.

- The accuracy of haul weights obtained from flow scale readings depends on the accurate accounting of the fish passing across the scale on a 24-hour basis, frequent calibration, and daily materials testing. At current observer staffing levels and sampling workload, independent verification of the accuracy of flow scale weights is not possible. Consequently, reliance on vessel personnel involvement is greater for the flow scale than other haul weight estimation methods.

- Bin and codend volumetric methods have the advantage of being independent estimates made by the observer that do not rely on electronic equipment maintained and operated by the vessel crew.

- Among volumetric methods of haul weight estimation, the bin volumetric method had the highest precision in the controlled setting of the research charter. No differences were detected between observers in applying this method. However, accurate bin volume estimates require that the amount of water in the bins be kept low.

- The codend volumetric method is less precise than the bin volumetric method, can show differences between observers, and may result in volume overestimation of codends larger than the vessel trawl alley. However, the codend volumetric method requires no specialized equipment, and is the easiest for the observer to obtain from a logistical perspective.

- Bin sensor volume estimates agreed closely with observer visual estimates when the level of the fish was at least 1.0 m below the transducers, but gave inaccurate readings when the bins were full or nearly full.

- The accuracy of all volumetric methods (i.e., codend, bin visual estimates, and bin sensors) is highly dependent on the use of the correct density factor. The current use of 0.93 $t/m^3$ as the density in pollock fisheries may underestimate haul weights by 5% for the bin volumetric method and 9% for the codend volumetric method.

- Several statistical approaches to estimating *in situ* density were evaluated. All gave similar results and suggest that the mean density of pollock in codends is 1.02 $t/m^3$, while the mean density of pollock in bins is 0.98 $t/m^3$. No significant differences in density were detected between the pollock A and B seasons.

- Evaluation of basket density estimates, the current procedure used by observers to estimate density, revealed significant differences between observers in applying the method. In contrast, density estimates obtained using the modified density sampler were consistent between observers and similar to the density of fish in bins.

## Recommendations

- If NMFS requires the use of flow scales to estimate total catch, adequate resources must be devoted to the evaluation of flow scales, monitoring at-sea test results, and auditing electronic records to identify improper uses of the flow scale.

- Successful application of the bin volumetric method requires accurate bin nomographs, accessible viewing windows, strong lighting to ensure visibility, multiple bin measuring strips, and minimal water in the bin during volume measurement. On many vessels in Alaska groundfish fisheries, these requirements are not presently met.

- The codend volumetric method is not appropriate for monitoring the catch of individual vessels, as in the Community Development Quota (CDQ) fishery, and should only be used when no other method is feasible.

- The use of bin sensors as a replacement for visual estimation cannot be recommended until further research is conducted on sensor calibration, testing procedures, and installation requirements needed to obtain accurate measurement of full bin volumes.

- For trawl hauls with greater than 95% pollock, a density of 1.02 $t/m^3$ for codends and 0.98 $t/m^3$ for bins is recommended.

- Further research using flow scales and density samplers is recommended to obtain density measurements for volumetric haul weight estimation in other groundfish fisheries. We recommend that density estimation using sampling baskets be discontinued, and that fishery-specific prescribed densities be used by observers.

## CONTENTS

# INTRODUCTION

## The role of haul weight estimates in fisheries management

The National Marine Fisheries Service (NMFS) North Pacific Groundfish Observer Program places 300-500 observers annually on fishing vessels and at processing plants in the Gulf of Alaska and the Bering Sea. The primary duties of observers are to estimate weight and species composition of groundfish catches. Management and assessment of the North Pacific groundfish fisheries relies extensively on the data collected by observers. These data are used by NMFS in conjunction with industry production reports to estimate weekly harvests for in-season fishery management and to estimate the annual removals of fish, shellfish, and other species for stock assessment.

Observers record an estimate of the total weight of each haul while they are on board a vessel. Haul weight estimates may be either independent estimates from measurements made by the observer or "eyeball" estimates made by the captain or fishing master. Since hauls may be brought on board at any time of the day, conflicting demands on observers' time prevent them from estimating all haul weights independently. A typical single observer on a factory trawler will be able to estimate the weight of 50-70% of the hauls. Haul weight estimates reported by observers are essential in the overall estimation of catch by species on catcher-processor trawl vessels and catcherboats delivering to motherships. Species composition sampling provides only an estimate of the proportion of each species in a haul. The catch by species is obtained by multiplying these proportions by the haul weight.

A "blend" of observer and industry data provides weekly estimates of total catch for in-season monitoring of groundfish quotas harvested by at-sea processors. At-sea processors are required to submit weekly production reports (WPR), consisting of processed product weight by species and product form, and estimated weights of discards by species. NMFS uses published product recovery rates to convert processed product weight to round weight. Total groundfish catch is computed each week for each processor vessel from the WPR. Corresponding weekly catch estimates are generated from observer data. If either report is missing, the report present is selected. If both reports are present, the "blend" algorithm is used to select either the WPR or observer estimates of weekly total catch. Selection criteria vary by target fishery and are explained in detail by Vølstad et al. (1997). Compiled over the year and combined with weighed landings reported by shoreside processors, these blend estimates become the annual record of catch used for stock assessment.

## Current haul weight estimation methods

Observers use either codend volume or bin volume estimates as the basis for determining the weight of each haul that they estimate independently. A fish density factor is multiplied by the estimate of catch volume to obtain an estimate of catch weight. A brief description of these methods follows.

**Codend volume method.** Observers measure the dimensions of a codend after it is brought onboard the vessel to determine the volume of fish in the net. This is done using pre-measured marks on the trawl deck, a meter stick, and/or a tape measure. Measurements are applied to a formula for the volumetric solid (rectangular, ellipsoidal, semi-ellipsoidal, or cylindrical) which best approximates the codend shape. Because codends may be large and irregular in shape, judgment is frequently required to estimate dimensions and determine codend shape.

**Bin volume determination.** Observers estimate the level of fish in the holding bins. Observers generally measure bins at the start of a deployment and use these measurements as the basis for determining volume from measurements of the height of fish. Some processors have holding bins that have been measured, marked, and certified by marine engineers ("certified bins"). Bin heights may be marked on the sides so that observers can view inside to determine the level of fish, or they may use reference points such as bin boards. Despite these markings, it is often necessary to judge the average height of fish since height may vary within a bin.

**Volume to weight conversion.** Fish density is used to convert volume to weight and is usually estimated by weighing a number of sampling baskets or other containers of unsorted fish. The volume of a full sampling basket is relatively small (0.055 $m^3$), whereas the volume of a bin or codend may exceed 100.00 $m^3$. Densities are calculated regularly and applied to sampled hauls with similar species composition. Currently, a NMFS-prescribed density of 0.93 metric tons per cubic meter ($t/m^3$) is applied to hauls that are greater than 95% walleye pollock. This prescribed density was set in the early 1990s based on an average of density measurements obtained by observers using sampling baskets.

**Preliminary work on the FT *Alaska Ocean* to evaluate haul weight estimation procedures**

Between August and October 1994, fieldwork was conducted on the FT *Alaska Ocean*, a factory trawler equipped with a motion-compensated belt-conveyor scale (flow scale). Haul weight estimates using codend and bin volume methods were compared with flow scale weights. Although the sample size was small (n=35), analysis of the data collected on the FT *Alaska Ocean* suggested that the density of pollock in fish bins was significantly higher than the NMFS-prescribed density of 0.93 $t/m^3$ (Dorn et. al, 1995). It was also shown that estimates based on bin volumes were generally more precise than codend estimates.

The recommendations resulting from research on the FT *Alaska Ocean* were: 1) conduct fieldwork to evaluate flow scale performance under field conditions; 2) conduct fieldwork to further evaluate volume-based haul weight estimation methods; and 3) further investigate the density factor used in volumetric catch estimation. Recommended research relating to the density factor included: using a flow scale to measure codend or bin weights directly and thereby obtain *in situ* density estimates, determining standard density factors for specific fisheries, evaluating the appropriate density sampling units (size, shape, volume), and developing a suitable device for density measurement by observers.

**Research objectives**

Although codend volume and bin volume methods have been used since the 1970s to estimate haul weights in at-sea fisheries in the North Pacific and the Bering Sea, the accuracy of these methods has never been evaluated. Haul weight estimates are dependent on both accurate volume measurement and the use of the appropriate volume to weight conversion factor. The current NMFS-prescribed density of 0.93 $t/m^3$ for pollock was obtained using relatively small sampling baskets which probably are not representative of the *in situ* densities in bins and codend. The use of flow scales to monitor catch weights is a potential improvement over these methods, but the technology was untested by NMFS in commercial fisheries. Ultrasonic bin sensors are another method for determining fish volumes in holding bins. Although this technology may be useful in situations where visual access to bins is difficult, it also had never been tested in a commercial fishery.

Specific objectives of this research project were to: 1) determine the accuracy of the flow scale used in this study and evaluate proposed test procedures for monitoring flow scale performance in production fisheries; 2) evaluate the accuracy of volume-based methods of catch weight determination using observer codend and bin volume measurements by comparing estimates obtained from these procedures with weight estimates obtained from a flow scale; 3) evaluate the use of ultrasonic bin sensors for determining fish volumes in holding bins; 4) obtain accurate *in situ* fish density factors to use in volume-to-weight conversions in the Bering Sea pollock A and B seasons; and 5) evaluate current and alternative methods used by observers to determine density.

## METHODS

The FT *American Triumph*, a 87 m factory trawler with surimi production capacity, was selected through a competitive bidding process as the platform on which to conduct this research. The FT *American Triumph* is operated by American Seafoods. Fieldwork was conducted in the Bering Sea during two phases which corresponded to the two annual pollock fisheries in the Bering Sea. The first phase, 23 August to 22 October 1996, included fishing during the second open access pollock fishery ("B season") for 1996. The second phase of the fieldwork was conducted 21 January to 10 March 1997, and included fishing during the first open access pollock fishery ("A season") for 1997. For the purposes of clarity throughout this manuscript, the first phase of research will be referred to as "1996-B season," and the second phase of research will be referred to as "1997-A season."

The research plan for each season was divided into three stages: pre-season and post-season stages conducted before and after the open access fishery, and an in-season stage conducted during the open-access fishery. The flow scale was calibrated and tested during the pre-season stage prior to the start of the open-access fishery. The main research was carried out during the in-season and post-season stages. The experimental design established a minimum sample size of 45 hauls within each of four haul size categories (i.e., <35 t, 35-70 t, 70-105 t, and

>105 t). Estimates of variability for sample size determination were derived from the preliminary fieldwork conducted on the FT *Alaska Ocean* (Dorn et al., 1995). Fishing was conducted as usual during the open access fishery, so the goal of measuring at least 45 hauls in the larger size categories was easily achieved (Table 1). To expand the range of codend volumes measured, the vessel was required to obtain the remaining hauls within the specified size categories during the post-season stage. The post-season stage was also used to fulfill similar requirements in obtaining a minimum of 24 bin volume measurements in each of the categories (i.e., $<30$ m$^3$, 30 - 60 m$^3$, 60 - 90 m$^3$, and $> 90$ m$^3$). The FT *American Triumph* was allowed to retain and process fish during the pre-season and post-season stages of the project.

A NMFS Field Party Chief and three experienced observers were placed on the vessel for the duration of the project. The Field Party Chief was responsible for conducting the daily flow scale tests, and working with the observers and ship personnel to ensure that sampling objectives were met. For each haul made by the FT *American Triumph* during the research project observers obtained 1) a codend volume estimate, 2) a bin volume estimate, 3) a species composition sample, 4) a pollock length frequency sample, 5) estimates of fish density using sampling baskets and a specially designed density sampler (described below), and 5) a flow scale weight. All codend and bin volume estimates were made by individual observers working independently.

To obtain this information at a high scientific standard, the vessel was required to follow procedures which deviated from normal operations on a factory trawler. Observers were allowed ample time to measure codends. The vessel was prohibited from mixing fish from different codends in the same bin. The use of water hoses to move fish into the bins was not allowed, thereby reducing the amount of water in the bins. Seawater was not added to the bins until after the observer had obtained a bin volume estimate. In addition, an observer sampling station was set up in the factory close to the conveyer belts leading from the bins. The sampling station included a work table, a Marel CP9140 [1] motion-compensated platform scale (100 kg capacity), and adequate floor space to store fish in sampling baskets for the flow scale material tests (defined below).

## Scale installation and testing

The National Marine Fisheries Service required that American Seafoods provide two types of scales for this study - a motion-compensated belt-conveyor scale or "flow" scale that could weigh all catch before sorting, discard, or processing and a motion-compensated platform scale to weigh samples and to test the flow scale. American Seafoods selected the Marel M2000-X01, P1450/900 flow scale and the Marel CP9140 platform scale.

The Marel M2000 is a self-contained belt-conveyor scale system that weighs fish or other

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

material as it is being conveyed across the weighing unit of the scale. The scale compensates for the affect of vessel motion by weighing an internal reference weight and adjusting the fish weights based on the difference between the known weight and the indicated weight of the reference weight. The Marel CP9140 platform scale employs the same motion-compensation technology to weigh material placed on the scale.

The flow scale was installed in the conveyor line that moved fish between the holding bins and the factory after the point where all fish flowed onto the conveyor and before any sorting of fish was done. Fish dropped approximately 20 cm from the factory's conveyor belt onto the in-feed plate section of the scale's conveyor belt. The scale was designed specifically for the FT *American Triumph* with a shorter and wider weighing area than most Marel flow scales, and with two weighing platforms side-by-side rather than a single weighing platform.[2] The flow scale was approximately 145 cm long by 105 cm wide with a weighing area that was 65 cm long by 90 cm wide. The maximum weighing capacity of the flow scale was 100 t per hour.

Vessel crew were instructed by the manufacturer to conduct a "marine calibration" procedure on the scale every 4 to 6 hours. The calibration consisted of placing a 10 kg weight on the weighing platform of the scale while the belt was not running and allowing the scale to perform an internal calibration procedure. Regular performance of this calibration procedure is necessary to ensure the proper performance of the scale. During the 1996-B season no information was collected by observers regarding calibration procedures performed by the crew. However, NMFS requested that the crew maintain a scale calibration log during the 1997-A season in order to evaluate the relationship between the timing and frequency of the calibration procedure and the performance of the scale.

A Marel technical representative was on board the vessel during the pre-season stage in the 1996-B season. He conducted initial materials tests of the scale and set the scale's internal calibration factor. This calibration factor was not changed during the remainder of the study.

NMFS specified that the flow scale must weigh test material to within 3% of its known weight and the platform scale must weigh standard test weights to within 1% of their known weight at all times during the study. Both the flow scale and the platform scale were tested at the beginning of each phase of the study to verify that they were weighing within the accuracy standards specified by NMFS and both scales were tested once each day during the study period.

The platform scale was tested each day by placing 30 kg and 40 kg test weights on the scale. This amount of test weight was chosen because the platform scale was being used primarily to weigh baskets of fish weighing between 30 kg and 40 kg each. Once the accuracy of the platform scale was verified, it was used to test the flow scale.

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[2]NMFS was not aware of the unique design of the scale with two weighing platforms until the A-season phase of the study. The potential consequences of this design on study results are discussed in a later section.

Two different methods of testing the flow scale were employed in this study: materials tests, and simulated load tests. Materials tests were conducted by weighing material of known weight on the flow scale. Fish used in materials tests were collected in baskets and weighed on the platform scale. Once all the baskets of fish were weighed on the platform scale, the fish was dumped onto the conveyor belt approximately 1 m in front of the flow scale and allowed to flow onto, across, and off the flow scale in the same manner that fish were conveyed across the scale in normal weighing. The percent difference between the known weight of the fish and the weight indicated by the flow scale was required to be within ± 3.0%. The percent difference between the known weight of materials and their flow scale weight will be referred to throughout this manuscript as "scale error." Materials tests are recommended as the official test of belt-conveyor scales by the National Conference of Weights and Measures in Handbook 44 (U.S. Department of Commerce, 1997).

To determine the amount of fish to use in the materials tests, NMFS considered the trade-off between the desirability of testing the scale with as large an amount of material as possible and the need to limit the time and energy required for the scale test. A "large" materials test using 1,000 kg of fish was conducted at the beginning of each pre-season phase to verify that the scale was weighing accurately. This amount was determined to be the largest amount of fish that could reasonably be collected and weighed when the processor vessel was not participating in a competitive, open-access fishery. Daily materials tests were conducted during both the pre-season and commercial fisheries. Only 400 kg of fish was used so that tests could be conducted in 15 minutes or less.

The simulated load test is conducted by placing a weight on the weighing platform of the scale, but not on the belt, so that the weight "accumulates" over a specific number of belt revolutions. A simulated load test was conducted immediately following each materials test. The test weight was a 15 kg steel bar that fit on the frame of the scale in contact with the weighing plate. During the 1996-B season, the belt was run for 6 belt revolutions (approximately 1 minute) and 15 belt revolutions (approximately 2 ½ minutes). The number of belt revolutions selected for the tests corresponded with the number required for the scale to accumulate approximately the same amount as was weighed in the materials tests (400 kg and 1,000 kg). The scale accumulated approximately 70 kg per belt revolution. This resulted in approximately 430 kg in the 6 revolution test and 1,050 kg in the 15 revolution test. One 6 revolution and one 15 revolution test was conducted each day. During the 1997-A season, only one simulated load test was conducted daily, but the duration of the test was extended to 30 belt revolutions (5 minutes). This change in the duration of the simulated load test was made at the recommendation of Marel in order to evaluate the effect of a longer test.

For purposes of this study, NMFS considered the materials test the official test to determine whether the flow scale was meeting the 3% accuracy standard. The simulated load test was conducted to analyze the relationship between the materials test results and the simulated load test results to determine whether it could be conducted in lieu of a materials test in the future. Because the simulated load test is simpler and faster to perform than a materials test, it would be preferred as a daily scale test if it adequately tested the scale's performance.

The percent error in the simulated load test was determined by comparing the cumulative weight at the end of each test with the expected result of the test based on an algorithm provided by Marel. The reference value for the simulated load tests is the product of the weight of the test weight (15 kg), the number of links in the belt (114 during 1996-B season, 113 during 1997-A season ), the scale's internal calibration factor (0.04170), and the number of belt revolutions (6, 15, or 30). Therefore, the reference values for the simulated load tests were as follows:

| No. of Revolutions | Reference Value (kg) |
|---|---|
| 6 | 427.842 |
| 15 | 1,069.605 |
| 30 | 2,120.445 |

During the 1997-A season study, sea condition at the time of the daily flow scale test was estimated by the Field Party Chief using the Beaufort Wind Force Scale (Appendix 1). This information was collected to analyze the relationship between vessel motion and scale test results.

**Codend volume estimates**

Observers followed procedures described in the Manual for Biologists aboard Domestic Groundfish Vessels (Teig 1996) for obtaining codend volume estimates (Appendix 2). The trawl alley on the FT *American Triumph* is 21 m in length and is separated into two 2.9 m wide lanes by a 1.0 m high center divider. Painted marks on the sides of the trawl alley were used to measure the length and height of the codend. All observers used the same marks. A tape measure was used to obtain the width of the codend, or the codend was determined to fill a lane and the width of the lane was used for the codend width. The formula for an ellipsoidal solid was usually used to calculate the volume, although other formulae described in the observer manual (Appendix 2) were occasionally used.

**Bin volume estimates**

The FT *American Triumph* has four fish holding bins. Two upper bins (port and starboard live tanks) with 50 $m^3$ capacity and a maximum depth of 1.9 m are located immediately below the trawl deck (Figs. 1 and 2). These upper bins fill separately from large hatches located towards the sides of the trawl alley at the aft end. Two lower bins (port and starboard refrigerated sea water tanks) with 120 $m^3$ capacity and a maximum depth of 4.0 m are located beneath the upper bins (Figs. 3 and 4). These lower bins fill from a small common hatch in the center the trawl alley at the aft end. This hatch leads to a small hopper (5 $m^3$), then to two chutes that drop the fish into the lower bins. The chutes can be opened and closed to direct the fish to a specific bin. All bins are approximately rectangular in horizontal cross-section, although the floors are sloping and irregular.

Prior to the research charter, glass viewing windows were installed in each bin. High-visibility yellow and black measuring strips were attached to the interior bin bulkheads. The measuring strips were constructed of laminated plastic (18 cm width) with alternating 10 cm bands in contrasting colors. The measuring strips were labeled in increments of 20 cm (numerals 5 cm in height). The interior measuring strips extended from the floor of the bin to the top, and were placed at approximately equal spacing on the bin bulkheads, but in locations where they could be seen from the viewing window. Measuring strips attached to the outside of the bin next to the viewing windows extended from the bottom to the top of the viewing windows. In the upper bins, 4 measuring strips were installed (6 in the 1997-A season), and in the lower bins, 5 measuring strips were installed (7 in the 1997-A season). Observers used a flashlight to read the height of fish on each measuring strip. Observer program procedures for estimating bin volumes are described in the observer manual (Appendix 2).

Nomographs of the fish bins on the FT *American Triumph* were prepared by Jensen Maritime Consultants (4241 21st Ave W, Seattle Wa, 98199). Nomographs are engineering drawings which provide both a diagram for plotting fish level readings to determine the average level of fish in the bin, and a table for converting average level of fish to volume. The observer records the level of fish at each visible marking strip and plots these points on the corresponding scales on the bin diagram. A line connecting these points is drawn, representing the slope of fish in the bin. The average level of fish in the bin is determined by the level at which this line intersects the centroid axis (geometric center of the bin) on the diagram. The table is used to convert average level of fish in centimeters to estimated volume of fish in cubic meters.

This method of estimating volume works best for fish that form a smooth surface in the bin. If fish are significantly mounded, it becomes more difficult to visually determine the average level of fish in the bin. Pollock generally form a smooth surface, although occasionally the level of fish is higher beneath the hatch were fish enter the bin, particularly if little water is present. This method is an improvement over the commonly used technique of averaging the readings from measuring strips, which does not account for the placement of the strips relative to each other and to the centroid axis of the bin. If the level of fish in the bin is sloping, the height of fish at centroid axis will not change, thereby providing an additional measure of robustness to the method.

Reliability codes were recorded for each bin volume estimate to evaluate the affect of mounding and water in the bin on volume estimates, as follows:

1. Fish flat to slightly mounded.
2. Fish significantly mounded or irregularly occupying the bin.

3. Fish extremely mounded or occupying only a small portion of the bin.
4. Substantial movement of fish in bins so that determination of height is difficult.
5. Bin is flooded with water.

During the 1996-B season portion of the research project, we discovered that normal operating procedures on the FT *American Triumph* could result in significant amounts of water draining into the fish bins when the codends were emptied, particularly for the upper bins. Since water may affect the estimate of fish volume in the bins, a number of changes were implemented between the 1996-B season and the 1997-A season to reduce the amount of water in the bins. Drainage holes were cut in the sides of the trawl alley to allow water to drain more easily, and we requested that the deck crew hold codends on deck for 5 minutes before emptying. Other changes were made between the 1996-B season and the 1997-A season to further improve the bin volume estimates: 1) the bin nomographs were checked and revised, 2) additional measuring strips were placed in each bin, and 3) a hand-held rechargeable 500,000 candle power spotlight was used to read the measuring strips rather than a flashlight lantern. Because of these changes, the results for the 1996-B season and the 1997-A season are not entirely comparable. However, increasing the accuracy of the 1997-A season bin volume estimates was the overriding concern.

**Bin sensor installation and recording procedures**

Ultrasonic bin level sensors were installed in the overhead (ceiling) of the lower port bin tank as an alternative method for determining the level of fish in the bin. The system provided by Milltronics, Inc. consisted of five Echomax XPS-10 ultrasonic signal transducers and an AirRanger XPL Plus transceiver. One transducer was installed in each corner of the bin overhead and one in the middle of the overhead, which meant that the casing containing the transducers protruded up into the floor of the upper port bin directly above the lower bin. This installation was necessary to provide space between the transducer and the fish when the bin was full, because the transducer cannot reliably measure distance when material is too close. The transceiver was mounted on the outside of the bin on the factory deck near the observer sampling station. The transducers were used to measure the distance from the face of the transducer to the nearest surface. The transceiver displayed distance measurements for each sensor and continuously updated this information.

Information about the level of fish in the bin was used in combination with a nomograph prepared specifically for the use of bin sensors in the lower port bin. The measurement scale for the bin sensor's nomograph started at the top of the bin and measured down to the bottom of the bin in order to correspond with the orientation of the bin sensors which measured distance from the transducer to the surface of the fish. Because the transducers were recessed, a correction factor was needed to adjust the transducer measurements to correspond to the nomograph scale. For example, if the bin were completely full the transducer should record the distance between the transducer and the fish as 20 cm, but the fish would be at a level corresponding with 0 cm on the nomograph indicating a completely full bin. Therefore, correction factors were determined by subtracting the height of the bin (as measured by the nomograph scale) from the distance between the transducer and the bottom of the bin (as measured in an empty bin). In this example, 20 cm would be subtracted from the bin sensor measurement before the distance measurement was plotted on the nomograph. Once the corrections were made to the distance measurements, the information from the bin sensors was applied to the nomograph in the same manner as described above for the visual level readings. Two sensors were mislabeled (switched) on the original nomograph. This problem was recognized and corrected during the 1996-B season.

Observers recorded several measurements from each bin sensor and selected the median as the distance measurement to use in the volumetric estimate. At the beginning of the 1996-B season, five readings from each sensor were taken. This number was increased to nine later in the season to reduce the influence of periodic erratic readings consisting of either a distance measurement very different from the others or an error message associated with a weak or undetectable signal.

**Density sampler and basket density estimates**

The prototype density sampler was designed to provide a more accurate estimate of fish density than can be obtained by following standard observer program procedures with sampling baskets. For the FT *American Triumph* research charter, it was possible to use codend and bin volumes and flow scale weights to estimate the density of fish in codends and bins directly. However, estimating fish density in other Alaska groundfish fisheries with this approach would be a large and expensive undertaking. The work with the prototype density sampler evaluated whether similar results can be obtained using a semi-portable device that can be operated by a single observer.

The density sampler was a 55 gallon plastic barrel, with a capacity of ~200 kg, mounted in a cradle ~1.0 m high that allowed it to be tilted and emptied (Fig. 5). Three rulers were attached to the inside of the sampler to allow precise measurements of fish volume. Based on our experience using the prototype density sampler during the 1996-B season, a number of design improvements were made prior to the start of the 1997-A season. The top 5 cm of the barrel, which tapered inwards slightly, was cut off, and a new lid was constructed to fit more snugly in the top of the barrel. The cradle was modified to permit the density sampler to be emptied more easily.

The density sampler was calibrated before each season by gradually filling the barrel with a known volume of water and recording the water level on each ruler. The calibration was checked at the end of the 1997-A season and found to have remained constant. The density sampler was operated by filling the sampler with fish taken directly from a conveyor belt running from the holding bins. The lid was placed on top of the fish, and volume was determined by measuring across from the top of the lid to the rulers. Volumes were obtained with no weight on the lid, and with 10 and 20 kg weights (20 and 50 kg weights during the 1997-A season; Appendix 3) placed on the lid to mimic the compression of fish in a bin or codend. The fish were then weighed on the Marel CP9140 motion-compensated platform scale.

Sampling basket density estimates were also obtained for each haul so that a comparison could be made between these two procedures. Basket densities were obtained by following procedures outlined in the Manual for Biologists aboard Domestic Groundfish Vessels (Teig 1996; Appendix 2).

## Analytical methods

Volume-based catch weight estimates depend upon two components: fish density and the measured volume of fish in a codend or bin. Therefore, in analyzing these data, questions about the bias of the volumetric component cannot be addressed separately from questions about the appropriate density for fish in the bins or in the codend. For this reason, our analysis examined the relationship between the volume estimates (in $m^3$) obtained with standard observer methods and the Marel flow scale weights (in t). Three statistical methods with different error assumptions were used to examine this relationship: least squares linear regression, functional regression, and a ratio estimator. Least squares linear regression and the related analysis of covariance assume error in the measurement of the dependent variable (flow scale weight) only. Functional regression assumes measurement error in both variables, flow scale weight and volume. Ratio estimates assume measurement error in flow scale weight, with the variance in flow scale weight proportional to volume. Relative precision of volumetric estimates was determined by comparing RMSE (square root of mean square error) in the reversed relationship where flow scale weight (no measurement error assumed) was the independent variable predicting codend or bin volume (measurement error assumed).

First, a least-squares linear regression model was used to explore the nature of the relationship between volume and flow scale weight. For each type of estimate (codend, bin, and bin sensor), we tested whether the relationship between volume and weight had a zero y-intercept, and examined the residuals for evidence of curvature in the relationship. The presence of a non-zero y-intercept or curvature in the relationship between volume and weight would indicate either that the density of fish changed with the volume of fish in the codend or bin, or that there was bias in the measurement of volume.

Because a codend or bin with zero volume has zero weight, an estimate of the appropriate codend or bin *in situ* density ($t/m^3$) is the slope of a zero-intercept linear regression (Neter et al. 1985),

$$y_i = \beta_1 x_i + \varepsilon_i ,$$

where $y_i$ = weight of haul i (t),
$x_i$ = volume of haul i ($m^3$),
$\beta_1$ = density ($t/m^3$),

and $\varepsilon_i$ = the weight measurement error of haul i.

The effects of individual observers, bin types, and bin reliability codes on the estimated weight-volume relationships were evaluated by analysis of covariance (ANCOVA). Two models were used to fully examine the effects of each covariate. In the first model, covariates were tested for both significant intercepts and differences in slope from an overall regression line with zero intercept (Freund et al., 1986):

$$y_{ij} = \beta_{0j} + (\bar{\beta}_1 - \beta_{1j})x_{ij} + \varepsilon_i ,$$

where $y_{ij}$ = weight of haul i in covariate group j (t),
$x_{ij}$ = volume of haul i in covariate group j ($m^3$),
$\beta_{0j}$ = intercept (main effect) for covariate group j,
$\bar{\beta}_1$ = average slope of zero-intercept regression (density, $t/m^3$),
$\beta_{1j}$ = difference in slope for covariate group j (density, $t/m^3$),
and $\varepsilon_i$ = the weight measurement error of haul i.

The hypotheses tested are $\beta_{0j} = 0$, $\beta_{1j} = 0$ for $j = 1,2,...n$ covariate groups.

An alternate model assumed zero intercepts for all covariates as well as the overall relationship, and tested for differences in slope:

$$y_{ij} = (\bar{\beta}_1 - \beta_{1j})x_{ij} + \varepsilon_i .$$

For this alternate model, the hypothesis tested is $\beta_{1j} = 0$ for $j = 1,2,...n$ covariate groups.

Although least squares regression is adequate to test for linearity in the weight-volume relationships and relative effects of covariates, it may be inadequate to estimate *in situ* codend and bin density due to error in the measurement of the volume. Therefore, *in situ* density was also estimated using the slope of a functional regression of weight on volume, which allows for measurement error in both variables (Kimura, 1992):

$$X_i = x_i + \delta_i ,$$

$$Y_i = \beta_{1f} X_i + \varepsilon_i ,$$

where $X_i$ = observed volume of haul i ($m^3$),
$x_i$ = true volume of haul i ($m^3$),
$\delta_i$ = volume measurement error of haul i ($m^3$),
$Y_i$ = observed weight of haul i (t),
$\beta_{1f}$ = density ($t/m^3$),
and $\varepsilon_i$ = weight measurement error of haul i (t).

Volume and weight measurement errors, $\delta_i$ and $\varepsilon_i$, are assumed to be independent, normal random variables with variances $\sigma_\delta^2$ and $\sigma_\varepsilon^2$. To fit a functional regression model by maximum likelihood, it is necessary to know $\lambda$, the ratio of the measurement error variances,

$$\lambda = \frac{\sigma_\varepsilon^2}{\sigma_\delta^2} .$$

Because estimating $\lambda$ for use in functional regression is the subject of some controversy (Ricker, 1973; Jolicoeur, 1975; Kimura, 1992), codend and bin *in situ* densities were estimated using functional regressions with $\lambda$ varied between 0.05 and 5.00 to examine the effect of $\lambda$. This range of $\lambda$ represents measurement error ratios from volume having 20 times more error than weight ($\lambda = 0.05$) to weight having 5 times more error than volume ($\lambda = 5$). It is likely that the true ratio of weight measurement error to codend and bin volume measurement error falls somewhere within this wide $\lambda$ range. Functional regression models by were fit by maximum likelihood using AD Model Builder (Fournier, 1996).

Additional estimates of *in situ* codend and bin density were made using ratio estimators (Cochran, 1977):

$$\hat{R} = \frac{\bar{y}}{\bar{x}} ,$$

where $\hat{R}$ = density ($t/m^3$),
$\bar{y}$ = mean weight for all hauls (t),
and $\bar{x}$ = mean volume for all hauls ($m^3$).

The variance of ratio estimates of density was calculated using the formula in Cochran (1977, p. 155, eq. 6.13):

$$var(\hat{R}) = \frac{1}{n\bar{x}^2}(s_y^2 + \hat{R}^2 s_x^2 - 2\hat{R}s_{xy}) ,$$

where $s_y^2$ = sample variance of weight (t),
$s_x^2$ = sample variance of volume ($m^3$),
$s_{xy}$ = sample covariance of weight and volume,
$n$ = number of hauls,
and all other variables are as described above.

Because the population of all possible hauls is very large compared to our sample sizes, the finite population correction (fpc) was not used in the variance formula.

## RESULTS

### Flow scale testing

The flow scale passed all materials tests, but flow scale weights showed a positive bias when compared with known weights measured on the platform scale. The range of scale error determined by materials testing was -1.4% to 2.7% overall (Fig. 6), indicating better precision than the allowable ±3% error. Materials tests indicated that mean scale error was 0.96%, and was not significantly different between the 1996-B (0.8%) and 1997-A (1.1%) seasons ($T = 1.73$, $df = 88$, $p = 0.089$). Although the mean scale error was significantly different from zero, the distribution of scale error was relatively symmetric with no extreme outliers for materials tests from both seasons (Fig. 7).

Materials tests indicated a significant trend in scale error over time during the 1996-B season, suggesting a "break in" period for the scale. Scale error increased over the course of the 1996-B season at approximately 0.02% per day, but showed no significant trend during the 1997-A season. Although the linear regression slope for the 1996-B season was highly significant ($p < 0.0001$), the fit of the data to a linear model was relatively poor ($r^2 = 0.28$). Because of the consistent positive scale error indicated by the materials tests, a correction factor was used to adjust the raw scale weights. To determine an appropriate correction factor, the increase in scale error over time was modeled using an asymptotic function for the 1996-B season (Fig. 8). The 1997-A season scale error was corrected using the overall mean error determined by materials testing. Corrected scale weights were used in subsequent analyses.

The simulated load test was not a good substitute for a materials test. No correlation was found between the results of materials and simulated load tests for either season. Four simulated load tests indicated that scale error exceeded the ±3% bounds during the 1996-B season, while concurrent materials tests indicated that scale error was within ±3%. Scale error determined by materials tests was generally positive, whereas simulated load test scale error was generally negative. Scale errors estimated by simulated load tests ranged from -7.72% to 2.37% over all tests and both seasons, with mean errors ranging from -1.18% for the 30 revolution test to -0.41% for the 15 revolution test. Materials tests showed increases in scale error over the course of the 1996-B season, while simulated load tests showed no significant scale error trend over the seasons.

The distribution of scale error estimated by simulated load tests had two modes during the 1997-A season (Fig. 7), indicating potential systematic bias. Differences between simulated load test scale errors appear to correlate with factory shifts (Fig. 9), suggesting differences in operation or calibration of the scale by shift personnel. Mean simulated load test scale error was significantly different by factory shift ($T = 6.52$, $df = 30.7$, $p = 0.0001$). Analysis of the 1997-A season materials testing by shift also revealed differences in scale error distribution, with a narrower range of scale error in Shift 1 (on duty 8:00 am-2:00 pm and 8:00 pm - 2:00 am) relative to Shift 2 (on duty 2:00 pm-8:00 pm), although there was no significant difference in mean materials test scale error by shift (T = 1.66, df = 41, p = 0.1172). No differences between shifts were detected during the 1996-B season.

Marine calibrations performed by the vessel crew did not appear to "degrade" significantly over periods of 1 to 12 hours. Correlations of flow scale error with time after calibration were non-significant for any scale test in either season. However, the Field Party Chief expressed uncertainty regarding the accuracy of the scale calibration record, so this test result may not be conclusive. The range of times between calibration and testing was 1 to 12.5 hours in the 1997-A season. Mean time between calibration and scale testing was 4 hours, 41 minutes in the 1997-A season and was not significantly different between shifts. Time since calibration ranged from 24 minutes to 18 hours in the 1996-B season, but times were recorded for only 10 out of 47 scale tests.

Scale error was unrelated to fish size. Although mode and median of fish length had small but significant correlations with scale error during the 1996-B season, this correlation disappeared when the increase in mean scale error over time was taken into account. Correlations of fish size and scale error were non-significant during the 1997-A season. A wider range of fish lengths (36 to 53 cm in the B season vs. 45 to 54 cm in the A season) was captured during the 1996-B season, with smaller fish captured earlier in the season, which may account for the differences in results. No effects of mean, variance, or range of fish lengths were significantly correlated with scale error at p = 0.05.

Vessel motion expressed as sea state on the Beaufort scale was uncorrelated with 1997-A season materials test scale error. During the 1997-A season, Beaufort sea state ranged from 2 (light breeze with no waves) to 8 (gale with 18 ft waves). The median Beaufort sea state was 4, a moderate breeze with 4 ft waves. However, the *change* in vessel motion (change in Beaufort sea state) was significantly correlated with the 1997-A season Shift 2 (on duty 2:00 pm-8:00 pm) simulated load test scale error, suggesting that potential differences between shifts in scale operation or calibration diminished the scale's motion compensation capability during Shift 2. Generally, Shift 2 simulated load test scale error was lower when vessel motion decreased in the time since the previous test (negative sea state change), and higher when vessel motion had increased in the time since the previous scale test (positive sea state change). Vessel motion had no effect on Shift 1 (on duty 8:00 am-2:00 pm and 8:00 pm - 2:00 am) simulated load tests. Vessel motion was not recorded during the 1996-B season.

## Evaluation of codend methods for catch weight estimation

Codend volumes were strongly related to flow scale weights over most of the range of volumes sampled. Linear models described the relationship reasonably well for both the 1996-B ($r^2 = 0.940$) and 1997-A seasons ($r^2 = 0.973$), although both regressions had small but significant positive y-intercepts (Table 2). Zero-intercept linear models also described the relationship well for both the 1996-B ($r^2 = 0.984$) and 1997-A seasons ($r^2 = 0.992$). However, residuals from the models were generally more positive for codend volumes below 100 $m^3$, and more negative when codend volumes exceeded 135 $m^3$ (Figs. 10 and 11). This slight curvature in the relationship along with the positive y-intercepts detected in the first model indicated either a reduction in density or an overestimate of volume for larger codends. Because smaller codends generally had shorter tow durations than larger codends (Fig. 12), a reduction in density with codend size could not be explained by longer tow durations "packing" the fish. Therefore, overestimation of volume in large codends is the best explanation for the positive intercepts and curvature in the weight-volume relationship.

Most problems with estimating codend volume occurred when codends exceeded the size of the trawl alley. Observers reported a variety of situations where codends were longer or taller than deck markings used for measurement, or where portions of the codend extended high into the net reel beyond the reach of measuring tapes. In these situations, the observers' methodology changed from measurement to estimation of the dimensions of the codend, and it appears that estimates were often slightly high. According to the dimensions of the trawl alley, codends over 135 $m^3$ were too large for accurate measurement on the FT *American Triumph*, and it is at 135 $m^3$ that curvature appears in the weight volume relationship. However, the relationship of scale weight to codend volumes under 135 $m^3$ were linear with reduced (1996-B season) or insignificant (1997-A season) y-intercepts (Table 2, Figs. 13 and 14), indicating little to no measurement bias in that codend size range.

Overestimation of volume for codends larger than the trawl alley may not be specific to the FT *American Triumph*. Because the size of the trawl alley is vessel specific, we will refer to codends with volumes over 135 $m^3$ as "larger than the trawl alley," and codends under 135 $m^3$ as "fitting in the trawl alley" in this manuscript. For subsequent analyses based on assumptions of linearity in the data, only data from codends fitting in the trawl alley were used. During the 1996-B season, 24 codends representing 22.4% of the catch by weight were larger than the trawl alley; during the 1997-A season, 53 codends representing 52.5% of the catch by weight were larger than the trawl alley. Relative to "correct" volumes predicted from scale weights (using the slope of the regression for codends fitting in the trawl alley for each season), volumes for codends larger than the trawl alley were overestimated by an average of 9.8% and 7.8% for the 1996-B and 1997-A seasons, respectively.

The problem of overestimation of codends larger than the trawl alley may not be as severe for the fleet as whole as for the FT *American Triumph*. Assuming the relationship of trawl alley size to vessel length is the same on all catcher-processor vessels, 123 codends were larger than the trawl alley out of 1029 codend volumes estimated by observers during the 1996-B season, representing 19.3% of the catch by weight. During the 1997-A season, 197 out of 861 codends, representing 27.5% of the catch by weight, were larger than the trawl alley.

There were differences between observers in the extent of codend measurement bias. Observer effects were detected in both seasons for all codend data and for codends fitting in the trawl alley by at least one of the ANCOVA models. In the 1996-B season, ANCOVA testing both intercepts and slopes for codends of all sizes found significant y-intercepts for observers P and Q but not observer R, and a significantly higher slope for observer R. However, when zero intercepts were assumed for all of the 1996-B season observers the differences in slope were not significant. There was little curvature in the weight-volume relationship for codends estimated by observer R, whereas relationships estimated by the other two observers showed more curvature (Fig. 15). Comparison of the RMSE (square root of mean square error) in the relationship where weight predicted volume indicated that observer R's codend volume estimates were also more precise than the other observers (RMSE = 8.1 vs. 12.1 and 12.1). During the 1997-A season, differences between observers were less obvious. When both intercepts and slopes were tested by ANCOVA, observers S and T had significant positive y-intercepts, but there was no significant difference between slopes. However, when zero intercepts were assumed for all of the 1997-A season observers, observer S had a significantly higher slope than observer T. 1997-A season observers had the same general precision in codend volume estimates (RMSE = 10.2, 10.5, and 10.0). Individual observer zero-intercept regression slopes for only codends fitting in the trawl alley were significantly different, ranging from 0.99 to 1.05 during the 1996-B season, and from 1.00 to 1.06 during the 1997-A season.

The precision of codend volume estimates was similar between seasons, although there appeared to be improvements in the 1997-A season. There was less curvature in the 1997-A season weight-volume relationship even though more codends larger than the trawl alley were landed in the 1997-A season (n=53) than in the 1996-B season (n=24). The overall RMSE for the 1997-A season codend volumes predicted by weight was 10.3, showing very slightly increased precision over the 1996-B season RMSE of 10.6. Observer P was on board the vessel in both seasons, and estimated codend volumes with less curvature and a lower RMSE in the 1997-A season (10.2) relative to the 1996-B season (RMSE=12.1). The increased precision in the 1997-A season have resulted from the requirement to retain codends on deck for 5 minutes to allow water to drain; the observers presumably had more time to measure the codend before it was dumped.

**Evaluation of bin volume methods for catch weight estimation**

Bin volume estimates were very precise, independent of the observer making them, and strongly related to scale measured weights over the range of volumes sampled. The RMSE in the relationship of bin volume predicted by weight was 4.4 for the 1996-B season and 3.2 for the 1997-A season, so the precision of bin volume estimates measured by RMSE is approximately double that of codend volume estimates in the pollock fishery. ANCOVA detected no differences between observers' bin volume estimates for either season. Individual observer RMSEs in the relationship where weight predicted volume were generally similar, but slightly more stable in the 1997-A season (3.1, 3.2, 3.2) than in the 1996-B season (4.1, 4.4, 5.5). Linear models described the relationship well for both the 1996-B ($r^2 = 0.983$) and 1997-A seasons ($r^2 = 0.993$), although the 1996-B season regression had a small but significant negative y-intercept (Table 2). Zero-intercept linear regression models described the relationship of weight to bin volume very well ($r^2 = 0.994$ in the 1996-B season, and 0.998 in the 1997-A season, Figs. 16 and 17). However, residuals from each season's models are slightly more negative for bin volumes below 55 $m^3$ and more positive over the range of 70 $m^3$ - 110 $m^3$. The ranges of volumes correspond to the respective differences in size between the upper bins (UB) and lower bins (LB). ANCOVA found significant differences between UB and LB regression slopes in both seasons, with the difference most pronounced in the 1996-B season.

Problems with bin volume estimation were caused by incorrect nomographs, water in the bins, and poor visibility (including blockage of the viewing window). Errors in the bin nomographs accounted for some of the difference detected between bin types. Comparison of the starboard UB nomographs revealed a mean 4.3% error in the 1996-B season relative to the 1997-A season, resulting in bin volume overestimates of 1 $m^3$ or more during the 1996-B season (starboard UB volumes were corrected for this error). No other bin nomographs were changed significantly between seasons. Water in the bins was a larger problem in the 1996-B season than in the 1997-A season. ANCOVA detected a significantly lower slope for bin volumes with reliability code 5 (flooded) than other reliability codes during the 1996-B season (Table 3), suggesting systematic volume overestimates due to water. (Conversely, ANCOVA detected significantly higher slopes for bin volumes assigned reliability code 1 than all other codes during both seasons; Table 3.) Although more bins were assigned reliability code 5 in the 1997-A season than in the 1996-B season, the difference in slope was not significant, suggesting differences between seasons in application of the bin reliability codes. Proportionally more water may have entered the smaller UBs than the larger LBs due to the hatch configuration on the deck, resulting in overestimates of UB bin volume relative to LB volume. Volume was overestimated in all of the bins during the 1997-A season when the viewing window was blocked; this left the observer no choice but to call the bin full and resulted in the apparent overestimates of volume clustered at 50 $m^3$ (full UB) and 120 $m^3$ (full LB; Fig. 17). Finally, it is possible that fish density is slightly greater in the deep LBs relative to the UBs due to compaction of fish, as separate regression models indicate (Table 4).

The 1997-A season bin volumes were more precise with less differences between bin types than the 1996-B season bin volumes due to improvements in estimation methods. The overall RMSEs listed above show increased precision in the 1997-A season bin volume estimates (3.2) relative to 1996-B season (4.4). Observer P (who was on board the vessel in both seasons) estimated bin volumes a lower RMSE in the 1997-A season (RMSE=3.2) relative to the 1996-B season (RMSE=4.4). The differences detected between bin types in the 1997-A season were greatly reduced relative to the 1996-B season (Table 4) because nomographs were corrected and measures were taken to reduce water in the bins.

## Evaluation of the bin sensor system

Several problems were encountered in the calibration and operation of the bin sensors. Determination of the correction factor for the bin sensors was difficult. Reliable measurements of the distance from the transducers to the bottom of the bin could not be obtained for all transducers because either the floor of the bin was sloped under the transducer or piping around the perimeter of the bin caused interference. In some cases, the correction factors were determined by having a person stand under the transducer with a large, flat disk held over his head. The total distance was determined by adding the height of the person, the thickness of the disk, and the measured distance from the transducer to the top of the disk. A more precise method of measuring the distance in the empty bin or alternative methods for initial calibration of bin sensors is needed if this technology is to be used for volumetric estimates in the future.

Unlike the flow scale, the bin sensors experienced mechanical failure during the course of the research. In one case, water from the upper bin started leaking in around a transducer causing it to malfunction. In the other case, a wire connecting a transducer to the transceiver was severed. Between the 1996-B and 1997-A seasons, Milltronics requested that all of the cables between the transceiver and the transducers be placed in grounded conduit to protect the electronic signals from interference.

Bin sensors agreed with visual (observer) volume estimates over the range of 20 - 100 $m^3$, but underestimated larger volumes relative to observer estimates, and never registered full (120 $m^3$) bin volumes. The 1996-B season linear regression of bin sensor volume on observer volume had a slope (0.9425) which was not significantly different from one and no significant y-intercept, indicating good overall agreement between observer and bin sensor volume estimates (Fig. 18). However, the 1997-A season regression had a significant positive y-intercept and a slope of 0.8769, which was significantly lower than 1 (Fig. 19). This indicated that the 1997-A season bin sensor estimates were lower than observer volume estimates for fuller bins. When bin volumes over 100 $m^3$ were excluded from the analysis, y-intercepts were non-significant and regression slopes for both seasons were not significantly different from one. Bin sensor estimates were less precise than observer estimates during the 1996-B season (RMSE=7.3 bin sensor vs. 4.4 observer), but each estimate type had similar precision in the 1997-A season (RMSE=4.1 bin sensor vs. 4.3 observer). Because both observer and bin sensor volume estimates were made with more precision in the 1997-A season due to improvements in equipment and methods, the underestimation of volumes over 100 $m^3$ by bin sensors was more obvious in the 1997-A season than in the 1996-B season (see regression residuals, Figs. 18 and 19). Although underestimation of bin volume by bin sensors appeared to start at 100 $m^3$, it was most severe over 110 $m^3$ when compared with observer estimated bin volume. The maximum bin sensor volume estimates were 113.3 $m^3$ and 113.8 $m^3$ in each season, while 5 and 22 observer volume estimates exceeded 114 $m^3$ in the 1996-B and 1997-A seasons, respectively.

When compared with scale weights, bin sensors also appeared to underestimate large bin volumes. The relationship of bin sensor volume to flow scale weight was linear over the range of 20-100 $m^3$, but poorly defined for bin volumes greater than 100 $m^3$ (Figs. 20 and 21). Linear regressions of weight in metric tons on bin sensor volume for each season had non significant y-intercepts with generally similar slopes for the 1996-B season and higher slopes for the 1997-A season than comparable regressions using observer estimated bin volume (Table 2). Elimination of volumes over 100 $m^3$ in the regression models resulted in reduced slopes more similar to those estimated using observer volumes during the 1997-A season.

## Density estimates using the density sampler

During the 1996-B season, density estimates ranged from 0.94 to 0.96 t/ $m^3$, while during the 1997-A season the range was from 0.97 to 0.99 t/$m^3$ (Table 5). Estimated density was significantly higher in the 1997-A season than in the 1996-B season for all comparable estimates (Table 6). Whether the difference between these estimates reflects a true difference in density between seasons cannot be determined due to the between-season modifications in the density sampler.

The density sampler was a substantial improvement over the basket method of estimating density. Although mean densities estimated by each method were comparable (Table 5), basket density estimates always differed by observer, while density sampler estimates were independent of the observer making them after the improvements to the density sampler between the 1996-B and 1997-A seasons (Fig. 22). Basket densities also appeared to decrease with time since capture ("capture" = codend on deck) during the 1997-A season, whereas density sampler estimates did not. There was a slight but significant negative correlation ($r = -0.1908$, $df = 174$, $p = 0.0112$) between time since capture and basket density in 1997-A season. The mean change in density with time for the 1997-A season basket estimates was -0.0023 t/$m^3$ per hour, so for the mean 1997-A season elapsed time of 6.5 hours the change in density was -0.015 t/$m^3$. Time since capture was uncorrelated with fish density for all estimate types in 1996-B season. Time between capture and density estimates ranged from 60 to 1058 minutes (mean 415 minutes) in the 1996-B season, and from 60 to 830 minutes (mean 390 minutes) in the 1997-A season.

## Catch characteristics correlated with density

Densities estimated using the density sampler during the 1997-A season appeared to be slightly affected by species composition. The 1997-A season density and percent pollock were slightly positively correlated for all estimate types, with correlations ranging from $r = 0.1717$ (basket estimates) to $r = 0.3234$ (density sampler, 20 kg on lid). The percentage of pollock ranged from 93.97% to 99.98% (mean 99.15%) in this season. The 1997-A season densities were also negatively correlated with the percentages of roundfish (other than pollock), flatfish, and soft invertebrates, because these bycatch categories were strongly negatively correlated with the percentage of pollock. The mean change in the 1997-A season density was approximately 0.005 t/$m^3$ per percent pollock increase, based on the strongest correlation estimated for the density sampler with 20 kg on the lid. No significant correlations between percent pollock or any bycatch category and density were found for basket or density sampler density estimates in the 1996-B season, where the percentage of pollock by haul ranged from 73.58% to 99.78% (mean 95.34%).

There was no significant correlation between mean pollock length and any density estimate in either season. Mean and range of fish lengths were similar for the 1996-B and 1997-A seasons (1996-B season: 47.93 mm mean, 34.91 - 52.86 mm range. 1997-A season: 47.1 mm mean, 39.08 - 54.16 mm range).

Bin density (total bin weight divided by total bin volume for each haul) was also used to examine *in situ* density relationships with date and species composition. Density may have increased slightly over the course of the 1997-A season, because bin density and all basket and sampler densities were positively correlated with the date. The 1997-A season hauls recorded beyond 03 March, 1997 were part of the post-season stage research fishery which occurred after the closure of the open access pollock fishery. The post-season research fishery coincided with the roe season when pollock were hydrating eggs in preparation for spawning, which may have increased pollock density. When the post-season research fishery hauls were eliminated from the data, bin density was still correlated with date while all basket and density sampler densities were uncorrelated with date. No correlation of density with date was found during the 1996-B season, indicating that density was stable throughout the period. The 1996-B season lasted 59 days, while the 1997-A season was 37 days long without the post-season research fishery and 45 days long including the research fishery.

Bin density also appears to be affected by species composition, but only for hauls with less than 95% pollock. Bin density was slightly positively correlated with percent pollock and negatively correlated with percent soft invertebrates (which included mostly jellyfish and some squid; more squid in the 1997-A season) for both seasons. However, there were no significant correlations with any aspect of species composition for hauls with 95% or more pollock in either season. For all hauls, the percentage of bycatch classified as soft invertebrates ranged from 0 to 17.1% in the 1996-B season and from 0.001 to 5.3% in the 1997-A season.

Species composition had a larger effect than date on bin density when all hauls were considered, but species composition had no effect on bin density for hauls with greater than 95% pollock. Multiple regression models were used to assess the relative importance of species composition and date to bin density. When all of the 1996-B season hauls were included, only soft invertebrate bycatch had a significant effect on density of -0.0082 t/m$^3$ for each percentage increase of invertebrates. For the 1996-B season hauls with over 95% pollock, no species composition or day factors had significant effects on bin density. In the 1997-A season, date had a smaller effect (0.00098 t/m$^3$ per day) on bin density measured in all hauls than invertebrate bycatch (-0.0200 t/m$^3$ per percent increase in invertebrates), but only date had an effect on bin density of hauls with greater than 95% pollock. The mean change in 1997-A season bin density with date for greater than 95% pollock hauls was 0.0012 t/m$^3$ per day including the research fishery, and 0.0017 t/m$^3$ per day excluding the research fishery.

### Comparison of various *in situ* density estimates

Codend *in situ* densities were estimated to be at least 1.00 t/m$^3$, higher than any other density (Figs. 23 and 24). Ratio estimates of codend density using all codend volumes were 1.00 t/m$^3$ in 1996-B season and 0.99 t/m$^3$ in the 1997-A season (Table 7). Ratio estimates of density for codends fitting in the trawl alley were 1.02 t/m$^3$ and 1.03 t/m$^3$ for the 1996-B and 1997-A seasons, respectively. The slope of the zero-intercept linear least squares regression where the volume of codends fitting in the trawl alley predicted scale weight in tons was 1.01 t/m$^3$ for the

1996-B season and 1.02 t/m$^3$ for the 1997-A season. Differences in codend and bin *in situ* density estimated using functional regression with $\lambda$ between 0.05 and 5 were trivial (Fig. 25), so $\lambda$ was set at 0.5 (measurement error variance of volume twice that of weight) for the remainder of analyses. The slope of a zero-intercept functional regression using the same data as for the least squares regression was 1.02 t/m$^3$ in the 1996-B season and 1.03 t/m$^3$ in the 1997-A season. The residuals from these linear models were randomly distributed over the entire range of volumes for codends fitting in the trawl alley, indicating no curvature (Figs. 13 and 14). Because no differences between seasons were detected, seasons were combined giving mean codend densities of 1.03 t/m$^3$ (ratio estimate) and 1.02 t/m$^3$ (least squares and functional regression estimates). Codend *in situ* density was significantly higher than density estimated in bins, baskets, or the density sampler, indicating that fish are under more pressure in codends than in bins. It is also possible that density measured in a small barrel can only approach the density of fish under high pressure in the codend with more than 50 kg of weight on the lid.

Bin *in situ* densities were estimated to be at least 0.98 t/m$^3$ (Table 8), although there was some evidence of density differences between bin types. The ratio estimate of bin density was 0.98 t/m$^3$ in both the 1996-B and 1997-A seasons. The slope of the zero-intercept linear regression where bin volume predicted scale weight in tons was 0.99 t/m$^3$ in the 1996-B season and 0.98 t/m$^3$ in the 1997-A season. Zero-intercept functional regressions also had slopes of 0.99 t/m$^3$ in the 1996-B season and 0.98 t/m$^3$ in the 1997-A season. As with codend densities, no differences between seasons were detected for any estimate. Combined season estimates are 0.98 t/m$^3$ (ratio estimate) and 0.99 t/m$^3$ (least squares and functional regression estimates). Differences between bin types in density estimates were pronounced in the 1996-B season, but relatively small in the 1997-A season. Upper bin densities estimated by least squares regression were generally reduced compared to lower bin densities (Table 4), suggesting a potential difference in density based on the relative sizes of the bins.

The 1997-A season density estimates were more stable across estimate types than the 1996-B season densities, in particular for density sampler and bin *in situ* estimates (Fig. 24). This may result from improvements in the density sampler and bin nomographs, the reduction of water in bins, and increased time for codend measurement between the 1996-B and 1997-A seasons. Although changes in methodology between seasons make it difficult to determine whether observed differences in mean density are real, the relative stability of the 1997-A season densities over all estimate types suggests that 1997-A season estimates are more reliable, and that the density sampler is capable of approximating *in situ* density for bins with 20 kg or more on the lid.

## DISCUSSION AND CONCLUSIONS

Before discussing results in detail, we believe that it is important to consider the extent to which these results can be generalized to all vessels and observers participating in pollock fisheries off Alaska. This project evaluates haul weight estimation methods as employed by experienced observers in a good sampling environment aboard one of the larger vessels in the fleet--since this is the only way that the observer's job can be standardized and made accessible to scientific study. The sampling environment is less conducive to accurate haul weight estimation on most other vessels in Alaska groundfish fisheries. In addition, first-time observers may be inexperienced in these techniques when they first arrive on a vessel, and may require some time to develop proficiency. Suboptimal sampling conditions and inexperienced observers could result in inaccuracies in haul weight estimates that our study was not designed to evaluate. Planning for this research forced us to identify the conditions necessary to obtain data of sufficient quality to evaluate observer haul weight estimates. An important byproduct of this project was a better understanding of the conditions required for a consistent standard of accuracy on a fleetwide basis.

This study evaluated the performance of a single flow scale made by one manufacturer. A full evaluation of flow scale performance on commercial fishing vessels would require placement of multiple units by different manufacturers on fishing vessels of different sizes. The use of flow scales is increasing as their advantages become apparent to the fishing industry in a regulatory environment where accurate catch estimates are required, such as in the CDQ fishery. We recommend that these developments be closely watched, and that performance data on other scales be collected as the opportunity arises, so that wider range of experience with flow scales can be acquired.

**Flow scale**

The flow scale materials tests indicated that the flow scale used in this project operated within established error limits through both seasons. Based on our experience during this research project, the Marel M2000 flow scale was reliable, trouble-free, and easy to operate in a seafood processing factory on a fishing vessel. However, the presence of a slight, but consistent, positive scale error detected by materials tests in both seasons indicates that standard calibration procedures did not remove the error. An initial calibration, such as was conducted during the pre-season phase of this project, should be required for flow scale use during commercial fisheries. The evidence of a break-in period during the 1996-B season where the mean scale error gradually increased indicates that a single test at the start of the season is not adequate to ensure scale accuracy throughout the season. Therefore, materials tests should be conducted daily throughout the season to ensure that any drift in scale error does not exceed acceptable limits. Information on flow scale error from materials tests may also be useful for post-season correction of catch weights, as was necessary in this study.

Although our research objectives did not include evaluation of different materials test weights, the daily materials tests of 450-500 kg with an allowance of ±3% deviation from known weight appeared to be sufficient to monitor flow scale performance without incorrectly failing the scale due to error in the test. Some percentage of the scale error indicated by the materials test may be due to the error in the test itself, and not error in the flow scale. For example, the platform scale weights of fish used as the known weight may have varied slightly due to vessel motion. A scale should not fail a materials test because the test itself is not very precise.

However, the range of observed scale error (from -1.4 to 2.7%, or ±2%) must be a bound on any error in the test itself, since it includes both the test error and the scale error. Therefore, the established error limits of ±3% should prevent test failure due to test error alone.

We were unable to validate the simulated load test as a substitute for a materials test, even though the simulated load test generally indicated that the scale was operating correctly. The reason for the lack of correlation between the results of the materials tests and the simulated load tests is unknown. However, it is likely due to the difference between how the test loads were applied to the scale in the tests. The simulated load test could not incorporate the effects of material flow across the scale or the effects of the loading and unloading of material from the belt. It was merely the accumulation of a constant load on the scale for a fixed number of belt revolutions. The materials test, on the other hand, reproduced the flow of fish that occurs in normal weighing operations. That is, an uneven load applied by the flow of fish and the length of belt travel were integrated by the scale to calculate cumulative weight. A Marel representative also suggested that the simulated load test may not have been appropriately designed for a scale with two weighing platforms because placement of the test weight on the outside frame of each of the weighing platforms could have exerted a vertical force on the weighing platforms that would have pushed them apart during the test (P. Jonsson, pers. comm. to S. Bibb via electronic mail on Jan. 1, 1997). Unfortunately, we did not know about the design of the scale in time to consider its impact on the simulated load test or to redesign the test to properly distribute the test weight across the weighing platforms.

The reason for the difference between factory shifts in the percentage error of the simulated load test is unknown. Since different workers operated and calibrated the scale during each shift, one possibility is that there were subtle differences in the calibration procedures and the frequency of calibration between shifts. The apparent sensitivity of the simulated load test to these differences suggests that the materials test is a more robust test of the scale. It also serves to highlight the importance of training factory personnel to operate the scale correctly, and the importance of frequent calibration of the flow scale.

Our experience with the flow scale during this project indicates that these scales can be used to obtain haul weight estimates to a high level of accuracy during a commercial fishery. In developing regulations for the use of flow scales, careful consideration should be given to the entire catch recording system. The accuracy of haul weights obtained from flow scale readings depends on accurate accounting of the fish passing across the scale on a 24-hour basis, frequent calibration, and daily materials testing. With one observer on a catcher/processor vessel and the current observer sampling workload, observers 1) would not be able to conduct an independent materials test, 2) would not be able to verify that the scale had been correctly adjusted or calibrated by vessel personnel, and 3) would not be able to verify that all fish had been properly weighed on the scale. Two observers would increase the time observers were in the factory and able to witness the use of the scale, but still would not provide sufficient monitoring to guarantee that accurate catch weights were being obtained from the scale at all times. Consequently, reliance on vessel personnel is greater for the flow scale than other haul weight estimation methods.

An additional benefit of the flow scale, which was not apparent at the start of this project, is its utility in bycatch sampling by observers. For relatively uncommon bycatch species like Pacific salmon, a sample size of ~20% of the total haul is needed to obtain reasonably accurate bycatch estimates on a haul-by-haul basis (Turnock and Karp 1997). This is a much larger sample size than can be weighed using standard observer sampling baskets. Since flow scales provide an continuous display of the cumulative weight that has passed across the scale, it is possible to obtain accurately weighed subsamples of a haul in the range of 5-20 t for species composition sampling of rare bycatch species.

**Codend estimates**

Our results show that the codend volume method is generally suitable for estimating haul weights--provided that the correct density factor is used to convert volume to weight. Since the sample size of codend estimates is large (1996-B season n = 213, 1997-A season n = 177), we were able to detect relatively subtle departures from linearity in the relationship of volume to weight. Two problems were identified with codend estimates: an apparent over-estimation of volumes for codends larger than the trawl alley, and significant differences between observers in the slope of the volume to weight relationship. Since there were differences between observers in the tendency to over-estimate volume, these two problems are interrelated. The 135 $m^3$ boundary between a linear volume to weight relationship and a curved relationship is probably specific to the FT *American Triumph*, and should not be generalized to other vessels.

Our results suggest that observers need better training in accurately estimating the volume of codends that extend beyond the trawl deck. In debriefing Observer R, whose codend estimates did not show bias at higher volumes, we learned that his measurements of codends larger than the trawl alley were obtained by climbing up the codend or the superstructure of the vessel to obtain a direct measurement of the ascending portion of the codend. We are reluctant to recommend this procedure for all observers. Identifying the potential problems of estimating the volume of codends larger than the trawl alley during observer training may reduce the tendency to over-estimate, as would developing specific estimation procedures for codends of this size.

Other methods of estimating the volume of codends larger than the trawl alley would require close cooperation between the deck crew and the observer, which may not be possible in the current regulatory environment. Although the 5 minute waiting period before emptying the codend during the 1997-A season was implemented on the FT *American Triumph* to improve the bin volume estimates, we found that it also gave the observer adequate time to take codend measurements without being pressured by the deck crew. Another possibility for improving the accuracy of the volume estimate would be for the deck crew to temporarily stop the retrieval of codends too long to lie flat in the trawl alley, and allow the observer to measure the codend in segments.

For codends fitting in the trawl alley, the range of zero-intercept slopes for individual observers was ±3.5% of the common zero-intercept slope, suggesting a bias of ±3.5% may occur in the catch estimates of individual vessels due to the observer on the vessel. This result was based on the estimates of experienced observers using identical deck markings, so the bias could easily be greater on other vessels. However, since the biases of individual observers would tend to average out across the fleet, this level of bias may be acceptable if the objective is to estimate fleet-wide removals. A bias of ±3.5% is probably unacceptable if accurate accounting is needed for individual vessels, as would be the case for vessels participating in the CDQ fishery.

Despite the problems that we identified with the codend volume method, codend estimates are probably the easiest for the observer to obtain from a logistical perspective, since the estimate is made at a single point in time when the entire catch is in one place. Codend volume estimates are also completely independent of any information provided by the vessel.

**Bin volume estimates**

In the relatively controlled setting of the research charter, the bin volume method was clearly the best of the two haul weight estimation methods currently used by the observer program. (Again, this is subject to the caveat that the correct density factor must be used to convert volume to weight). The relationship of bin volume to weight was very linear throughout the range of bin volumes, and no effects due to individual observers were detected. A comparison of the RMSE of the two methods showed that bin volume estimates were more than twice as precise as codend estimates.

The primary drawback of the bin volume method is the difficulty of ensuring that conditions necessary for accurate volume estimates can be achieved on commercial fishing vessels. The terms of the research charter gave us sufficient leverage to require the crew to follow procedures that reduced the amount of water mixed with fish in the bins to the minimum amount possible under commercial fishing operations. Notwithstanding, the ANCOVA using reliability codes detected a significant reduction in the apparent density due to the presence of water in the bins. We also strongly suspect that change in the apparent density of pollock for the shallower upper bins between the 1996-B and 1997-A seasons was due to the additional procedures we instituted to reduce the water in the bins. If the amount of water mixed with the fish is sufficient to float the fish in the bin, a bin volume estimate is of no value.

The reduction in RMSE between the 1996-B and 1997-A seasons indicates that it is possible to improve the precision of bin volume estimates by improving sampling conditions. Accurate bin volume estimates require accurate bin nomographs, multiple measuring strips, viewing windows that provide an unobstructed view of those strips, and the ability to illuminate the measuring strips so that they can be read easily. Unless these requirements can be made standard on a fleet-wide basis, the bin volume estimates may not be as reliable as we found them to be during the research charter.

**Bin sensor estimates**

In evaluating the bin sensors it is necessary to consider separately the technology of bin sensors and the particular aspects of the installation of bin sensors on the FT *American Triumph.* The results showed a close correspondence between bin sensor volume estimates and observer visual estimates of volume for bin volumes less than 100 $m^3$. Since the bin sensors gave readings towards the center of the bin, while visual readings were obtained from measuring strips around the perimeter of the bin, their correspondence increases our confidence in both methods, and suggests that both methods are acceptable methods of estimating bin volumes.

However, the analysis of the bin sensor volume estimates indicate that the bin sensors did not give accurate readings if fish were too close to the transducers. On the FT *American Triumph*, the transducers were recessed 25 cm in the top of the bin, but bin sensors seldom gave readings that low even when observers reported that the fish were clearly filling the bin. It is possible that if the sensors were always at least 1 m away from the top of the fish, no bias would have been detected. This might be achieved by not filling the bins completely full (a difficult requirement to satisfy during commercial fishing operations), or by further recessing the sensors in the top of the bin.

Several bin sensors failed to operate correctly during the course of the charter, but again this is probably due to a poor installation rather than any general lack of reliability of the bin sensor system. The electrical conduits for the transducers that protruded from the floor of the upper port bin passed through the upper bin to the display unit. These elements of the system were exposed to considerable mechanical stress and potential for water seepage. The bin sensor failures occurred when the electrical connections to the transducers severed or shorted out, and were easily repaired.

Overall, there are no apparent advantages to using bin sensors over visual estimates for bins in which the observer can see the level of fish throughout the bin. Both are subject to the same potential drawbacks, including a potential bias due to water in the bins, and a dependency on bin nomographs whose accuracy is not independently verified. Installation of bin sensors should ensure that the sensors are sufficiently recessed to register full bin volume, and that they are adequately protected from water seepage. Bin sensors have a potential application when visual access to bins is difficult. However, because of the problems we encountered with bin sensors not registering full bin volumes along with other installation and calibration problems, we recommend that additional tests be conducted before accepting bin sensors as a valid haul weight estimation method.

A comparison of the different methods of haul weight estimation that were evaluated in this research project is given in Table 9.

**Density sampler and basket densities**

Several significant problems were found with density estimates from sampling baskets, the method currently used by the observer program. The first problem was the lack of consistency between observers in the estimated densities. Had the observers been on different vessels, it would be possible to argue that the density varied from vessel to vessel. However, for this research project, each observer was estimating density using fish with similar characteristics. Based on our debriefings of the observers involved in this project, these differences were likely to due to the subjectivity of the volume determination, and differences in how the observer arranges the fish in the basket. The *in situ* codend and bin densities were not significantly different for the 1996-B and 1997-A seasons, yet the mean basket density increased by about 4% from the 1996-B season to the 1997-A season. Standardization of basket density sampling procedures may produce more similar density estimates from different observers. For example, during the 1997-A season we requested that all the observer fill their baskets to the same height (to the base of the handle), which may explain why the basket density estimates were more similar than during the 1996-B season.

The other major problem with basket density estimates is that they do not correspond to the *in situ* densities estimated from flow scale weights and bin or codend volumes--particularly for the 1996-B season data. The reasons for this discrepancy are most likely twofold: first, the compression of fish that occurs in a bin or codend does not take place in a small sampling basket; and second, some fish are too large to fit in observer baskets in the same way that they fit in a codend or bin. Because of these problems, we recommend discontinuation of the use of sampling baskets by observers to estimate density. For target fisheries where *in situ* density estimates are unavailable, a precautionary approach would be to fix density at a conservative value (e.g. 1.0 $t/m^3$) until additional data are available.

Our work with the prototype density sampler indicated that it was possible to design and operate semi-portable unit that eliminates most of the drawbacks of basket sampling. With the density sampler, volume is actually measured rather than estimated, and the volume of the container is approximately four times the volume of a sampling basket. It is still much smaller than a bin or a codend. Because of the modifications in the density sampler subsequent to the 1996-B season, we do not have a high level of confidence in the 1996-B season density sampler estimates. After the modifications, the density estimates for different observers were highly consistent. For the 1997-A season, the density estimates using the density sampler generally gave similar results to the *in situ* bin density when a 20 kg weight was placed on the lid. A 50 kg weight was not sufficient to approximate the *in situ* density in codends, suggesting that more weight is required. Additional experimentation with heavier weights is needed to determine whether the density sampler can obtain densities similar to the *in situ* codend density. The increase in density with additional weight on the lid clearly demonstrates the effect of compression on density, and provides an explanation of why basket density estimates are inaccurate.

The *in situ* pollock density estimates for codends and bins obtained in this research are the most reliable estimates of density for the pollock fishery. Consequently, density sampler densities are not necessary to provide recommendations for the density factor for the pollock fishery, although they do provide supporting evidence. The primary application of the density sampler research is in other fisheries for which no accurate density estimate is available. We recommend additional density samplers be constructed and deployed with observers in other target fisheries. The data collected would allow NMFS to produce a table of densities to be used in other groundfish fisheries off Alaska.

We also used the density sampler and basket densities to evaluate whether other factors affected density. Most of the factors that we examined were either not significant or had fairly weak and inconsistent effects on density. For example, when time since capture was evaluated, we found a significant decline only in the basket-estimated densities for the 1997-A season, and not for any other data set. No effect of fish size was detected in either season. The percent pollock in the catch had a relatively small but significant effect for all data sets during the 1997-A season only, and indicated that over the range of 95-100% pollock, density is likely to vary no more than 2.5%. Since the catch on the FT *American Triumph* was fairly representative of other vessels, from a strategic standpoint it is probably ill-advised to make slight adjustments in the density which would tend to average out over the season.

**Recommended density factors for pollock fisheries**

Observations of live pollock in their natural environment indicate that they are neutrally buoyant in seawater, which has a density of a 1.02-1.03 kg/m$^3$. Pollock maintain neutral buoyancy by adjusting the volume of gas in their swimbladder. After capture, other factors may affect the physical density of pollock. When fish are brought to the surface in a net, the rapid reduction in water pressure can cause their swimbladders to decompress. Codends containing pollock are usually buoyant in the water before being brought on board. Gradual deflation of swimbladders after the fish have been landed would tend to increase the density. The density of fish in bins and codends would also be affected by the shape and rigidity of the fish. Fish that do not pack together well would tend to have lower densities because of the interstitial spaces between the fish. In both bins and codends, the weight of fish pressing down would cause compression, which would decrease the interstitial spaces and thus increase density. The density of seawater should be close to an upper bound of pollock density in bins and codends.

In estimating a density factor appropriate for converting a bin or codend volume to weight, we are not as interested in the true density of pollock as we are in obtaining a conversion factor which converts volume, as determined by observers, to haul weight. For example, if observers always overestimated volume by 50% (an extreme example), an estimate of the density conversion factor derived from the biased observer volume estimates and flow scale weights would *still* result in an unbiased estimate of haul weight. The *in situ* density estimates--ranging from 0.98 for bins to 1.02 for codends--are plausible values for the true density for pollock, and therefore suggest that the volume estimates made by observers are not seriously biased.

Density factors should account for significant and consistent differences in density, but should not be so complicated that observers have difficulty in identifying the appropriate density factor to use for a haul. Since no significant differences were detected in the *in situ* densities for the 1997-A and the 1996-B seasons, a single density for both seasons should be used. However, the difference in density between codends and bins was significant and fairly consistent for both seasons, so it is appropriate to use different density factors for bins and codends.

Based on the combined season *in situ* density estimates, a density of 0.98 $t/m^3$ for bins is recommended. All of the combined season density estimators were very similar and were clustered around 0.98 $t/m^3$. Although there were fairly consistent differences in density between the shallow upper bins, and the deeper lower bins, we do not find our results compelling enough to recommend that bin density factor should take into account the depth of fish in bins. The most reliable data (for the 1997-A season) suggests that density may increase from ~0.96 $t/m^3$ in bins less than 2.0 m deep (upper bins) to ~0.98 $t/m^3$ at depths greater than 2.0 m deep (lower bins). However, there was some variation between individual bins, with the upper port bin densities nearly equal to lower port bin densities during the 1997-A season, while the lower starboard bin densities were 3.6% higher than the upper starboard bin densities. We suspect that the differences between the upper and lower bins are largely due to the relative amount of water present in each bin. The 1997-A season density sampler mean density with zero weight was 0.97 $t/m^3$ , suggesting bin density should be no lower than 0.97 $t/m^3$. On most vessels a range of fish depths in bins will be encountered over the season, so that potential differences in bin density with fish depth would tend to average out.

For codends, the combined season density estimates for codends fitting in the trawl alley are clustered around a value of 1.02 $t/m^3$. Although some observers tended to overestimate the volume of larger codends, this was not consistent for all observers. This problem should be addressed by improved training to educate observers about the potential for overestimation, and by developing procedures to ensure that only quantitative estimates are made of larger codends.

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Table 1. Sample size goals and actual number of hauls sampled within codend weight and bin volume categories for the 1996-B season and 1997-A season on the FT *American Triumph.*

1996-B season

| Codend weight category (t) | Sampling goal | Number sampled |
|---|---|---|
| < 35 | 45 | 45 |
| 35 - 70 | 45 | 61 |
| 70 - 105 | 45 | 62 |
| > 105 | 45 | 45 |
| Total | 180 | 213 |

| Bin volume category ($m^3$) | Sampling goal | Number sampled |
|---|---|---|
| < 30 | 24 | 68 |
| 30 - 60 | 24 | 88 |
| 60 - 90 | 24 | 61 |
| > 90 | 24 | 56 |
| Total | 96 | 273 |

1997- A season

| Codend weight category (t) | Sampling goal | Number sampled |
|---|---|---|
| < 35 | 45 | 33 |
| 35 - 70 | 45 | 36 |
| 70 - 105 | 45 | 36 |
| > 105 | 45 | 72 |
| Total | 180 | 177 |

| Bin volume category ($m^3$) | Sampling goal | Number sampled |
|---|---|---|
| < 30 | 24 | 52 |
| 30 - 60 | 24 | 112 |
| 60 - 90 | 24 | 32 |
| > 90 | 24 | 83 |
| Total | 96 | 279 |

Table 2. Linear regression results for codend volume to weight, bin volume to weight, and bin sensor volume to weight relationships. For each volume estimate type, the intercept model is presented first, followed by the zero-intercept model.

1996-B season

| Volume estimate | Parameter | Parameter estimate | Standard error | t | p value |
|---|---|---|---|---|---|
| Codend | Intercept | 6.401 | 1.316 | 4.863 | 0.0001 |
| | Slope | 0.910 | 0.016 | 57.836 | 0.0001 |
| | Slope | 0.976 | 0.009 | 114.265 | 0.0001 |
| Codend < 135 $m^3$ | Intercept | 3.813 | 1.354 | 2.817 | 0.0054 |
| | Slope | 0.961 | 0.019 | 49.501 | 0.0001 |
| | Slope | 1.009 | 0.009 | 106.807 | 0.0001 |
| Bin | Intercept | -3.092 | 0.538 | -5.746 | 0.0001 |
| | Slope | 1.032 | 0.008 | 124.450 | 0.0001 |
| | Slope | 0.991 | 0.004 | 223.497 | 0.0001 |
| Bin sensor | Intercept | -3.765 | 3.097 | -1.216 | 0.2281 |
| | Slope | 1.027 | 0.035 | 28.965 | 0.0001 |
| | Slope | 0.985 | 0.010 | 101.884 | 0.0001 |
| Bin sensor < 100 $m^3$ | Intercept | -2.347 | 2.507 | -0.936 | 0.3537 |
| | Slope | 1.003 | 0.033 | 30.855 | 0.0001 |
| | Slope | 0.974 | 0.009 | 107.164 | 0.0001 |

Table 2 continued. Linear regression results for codend volume to weight, bin volume to weight, and bin sensor volume to weight relationships. For each volume estimate type, the intercept model is presented first, followed by the zero-intercept model.

1997-A season

| Volume estimate | Parameter | Parameter estimate | Standard error | t | p value |
|---|---|---|---|---|---|
| Codend | Intercept | 5.927 | 1.350 | 4.390 | 0.0001 |
| | Slope | 0.927 | 0.012 | 79.096 | 0.0001 |
| | Slope | 0.971 | 0.007 | 145.703 | 0.0001 |
| Codend < 135 $m^3$ | Intercept | 2.201 | 1.402 | 1.570 | 0.1191 |
| | Slope | 0.997 | 0.020 | 51.077 | 0.0001 |
| | Slope | 1.024 | 0.010 | 107.702 | 0.0001 |
| Bin | Intercept | -0.323 | 0.368 | -0.876 | 0.3815 |
| | Slope | 0.985 | 0.005 | 192.287 | 0.0001 |
| | Slope | 0.981 | 0.003 | 377.638 | 0.0001 |
| Bin sensor | Intercept | -4.043 | 2.060 | -1.963 | 0.0545 |
| | Slope | 1.063 | 0.023 | 47.099 | 0.0001 |
| | Slope | 1.020 | 0.006 | 173.058 | 0.0001 |
| Bin sensor < 100 $m^3$ | Intercept | -2.005 | 1.406 | -1.426 | 0.1650 |
| | Slope | 1.029 | 0.020 | 51.799 | 0.0001 |
| | Slope | 1.002 | 0.005 | 201.674 | 0.0001 |

Table 3. Comparison of weight-volume relationships by bin reliability code. Reliability code 1 = fish flat, code 2 = fish slightly mounded or irregularly occupying the bin, code 3 = fish significantly mounded or occupying a small part of the bin, code 4 = substantial movement of fish in bins--height determination difficult, code 5 = bin flooded with water.

1996-B season

| Reliability code | Number of bins | Zero intercept regression slope | Standard error | p value (ANCOVA vs. other codes combined) |
|---|---|---|---|---|
| 1 | 161 | 0.998 | 0.006 | 0.0174 |
| 2 | 47 | 0.997 | 0.009 | 0.9883 |
| 3 | 14 | 1.015 | 0.010 | 0.5039 |
| 4 | 12 | 0.922 | 0.027 | 0.2395 |
| 5 | 26 | 0.942 | 0.014 | 0.0343 |

1997-A season

| Reliability code | Number of bins | Zero intercept regression slope | Standard error | p value (ANCOVA vs. other codes combined) |
|---|---|---|---|---|
| 1 | 181 | 0.987 | 0.003 | 0.0313 |
| 2 | 3 | 1.006 | 0.023 | 0.6893 |
| 3 | 6 | 1.071 | 0.110 | 0.8454 |
| 4 | 15 | 0.987 | 0.006 | 0.5221 |
| 5 | 64 | 0.967 | 0.006 | 0.1914 |

Table 4. Comparison of zero intercept least squares regression models by bin type. UB = upper bin, LB = lower bin, P = port, S = starboard.

1996-B season

| Bin type | Slope | Standard error | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| UB (combined) | 0.916 | 0.009 | 0.897 | 0.934 |
| LB (combined) | 0.999 | 0.005 | 0.989 | 1.010 |
| PUB | 0.934 | 0.016 | 0.903 | 0.964 |
| SUB | 0.899 | 0.010 | 0.879 | 0.919 |
| PLB | 0.991 | 0.006 | 0.980 | 1.003 |
| SLB | 1.009 | 0.009 | 0.991 | 1.026 |

1997-A season

| Bin type | Slope | Standard error | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| UB (combined) | 0.963 | 0.005 | 0.954 | 0.973 |
| LB (combined) | 0.983 | 0.003 | 0.976 | 0.990 |
| PUB | 0.970 | 0.006 | 0.957 | 0.982 |
| SUB | 0.957 | 0.007 | 0.943 | 0.972 |
| PLB | 0.972 | 0.006 | 0.961 | 0.983 |
| SLB | 0.993 | 0.004 | 0.985 | 1.001 |

Table 5. Summary of basket and density sampler density estimates

1996-B season

| Method | Density | Standard error | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| Baskets | 0.953 | 0.003 | 0.947 | 0.958 |
| Density sampler with 0 kg | 0.939 | 0.002 | 0.935 | 0.942 |
| Density sampler with 10 kg | 0.950 | 0.002 | 0.946 | 0.953 |
| Density sampler with 20 kg | 0.959 | 0.002 | 0.956 | 0.962 |

1997-A season

| Method | Density | Standard error | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| Baskets | 0.992 | 0.002 | 0.988 | 0.997 |
| Density sampler with 0 kg | 0.970 | 0.002 | 0.967 | 0.973 |
| Density sampler with 20 kg | 0.980 | 0.001 | 0.977 | 0.983 |
| Density sampler with 50 kg | 0.992 | 0.002 | 0.989 | 0.995 |

Table 6. Differences between seasons in basket and density sampler density estimates

| Method | 1996-B season | 1997-A season | t | df * | p value |
|---|---|---|---|---|---|
| Baskets | 0.953 | 0.992 | -11.202 | 383.835 | 0.0001 |
| Density sampler with 0 kg | 0.939 | 0.970 | -12.878 | 389.211 | 0.0001 |
| Density sampler with 20 kg | 0.959 | 0.980 | -9.718 | 389.851 | 0.0001 |

*assuming unequal variances

Table 7. Summary of *in situ* codend density estimates

1996-B season

| Method | Density | Standard error | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| Ratio estimate (all data) | 0.999 | 0.010 | 0.979 | 1.019 |
| Ratio estimate (volume < 135 $m^3$) | 1.023 | 0.011 | 1.002 | 1.044 |
| Zero intercept least squares regression (volume < 135 $m^3$) | 1.009 | 0.009 | 0.990 | 1.027 |
| Zero intercept functional regression (volume < 135 $m^3$) | 1.020 | 0.010 | 1.001 | 1.032 |

1997-A season

| Method | Density | Standard error | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| Ratio estimate (all data) | 0.989 | 0.008 | 0.973 | 1.006 |
| Ratio estimate (volume < 135 $m^3$) | 1.032 | 0.011 | 1.011 | 1.054 |
| Zero intercept least squares regression (volume < 135 $m^3$) | 1.024 | 0.010 | 1.005 | 1.043 |
| Zero intercept functional regression (volume < 135 $m^3$) | 1.032 | 0.010 | 1.013 | 1.050 |

Seasons combined

| Method | Density | Standard error | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| Ratio estimate (all data) | 0.994 | 0.006 | 0.981 | 1.006 |
| Ratio estimate (volume < 135 $m^3$) | 1.027 | 0.008 | 1.011 | 1.042 |
| Zero intercept least squares regression (volume < 135 $m^3$) | 1.015 | 0.006 | 1.002 | 1.028 |
| Zero intercept functional regression (volume < 135 $m^3$) | 1.025 | 0.007 | 1.011 | 1.038 |

Table 8. Summary of *in situ* bin density estimates

1996-B season

| Method | Density | Standard error | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| Ratio estimate | 0.977 | 0.005 | 0.966 | 0.987 |
| Zero intercept least squares regression | 0.991 | 0.004 | 0.982 | 1.000 |
| Zero intercept functional regression | 0.994 | 0.004 | 0.986 | 1.003 |

1997-A season

| Method | Density | Standard error | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| Ratio estimate | 0.979 | 0.003 | 0.973 | 0.985 |
| Zero intercept least squares regression | 0.981 | 0.003 | 0.976 | 0.986 |
| Zero intercept functional regression | 0.982 | 0.003 | 0.977 | 0.987 |

Seasons combined

| Method | Density | Standard error | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| Ratio estimate | 0.978 | 0.003 | 0.972 | 0.984 |
| Zero intercept least squares regression | 0.985 | 0.002 | 0.980 | 0.990 |
| Zero intercept functional regression | 0.986 | 0.003 | 0.983 | 0.992 |

Table 9. Comparison of haul weight estimation methods.

| | | | | FT *American Triumph* research charter results | | | |
|---|---|---|---|---|---|---|---|
| Haul weight estimation method | Cost to implement | Density factor needed? | Accurate bin drawings needed? | Precision | Significant observer effect? | Reliance on vessel personnel | Biases detected |
| Codend volume | None | Yes | No | Low | Yes | Low | a) Overestimation of volume of large codends. |
| Bin volume (visual) | Low-moderate | Yes | Yes | High | No | Moderate | a) Overestimation of volume due to water in bins, b) Inaccurate bin drawings. |
| Bin sensors | High | Yes | Yes | High | No | Moderate | a) Overestimation of volume due to water in bins, b) Inaccurate bin drawings. |
| Flow scale | High | No | No | Very high | No | High | a) Consistent percent error in scale readings |

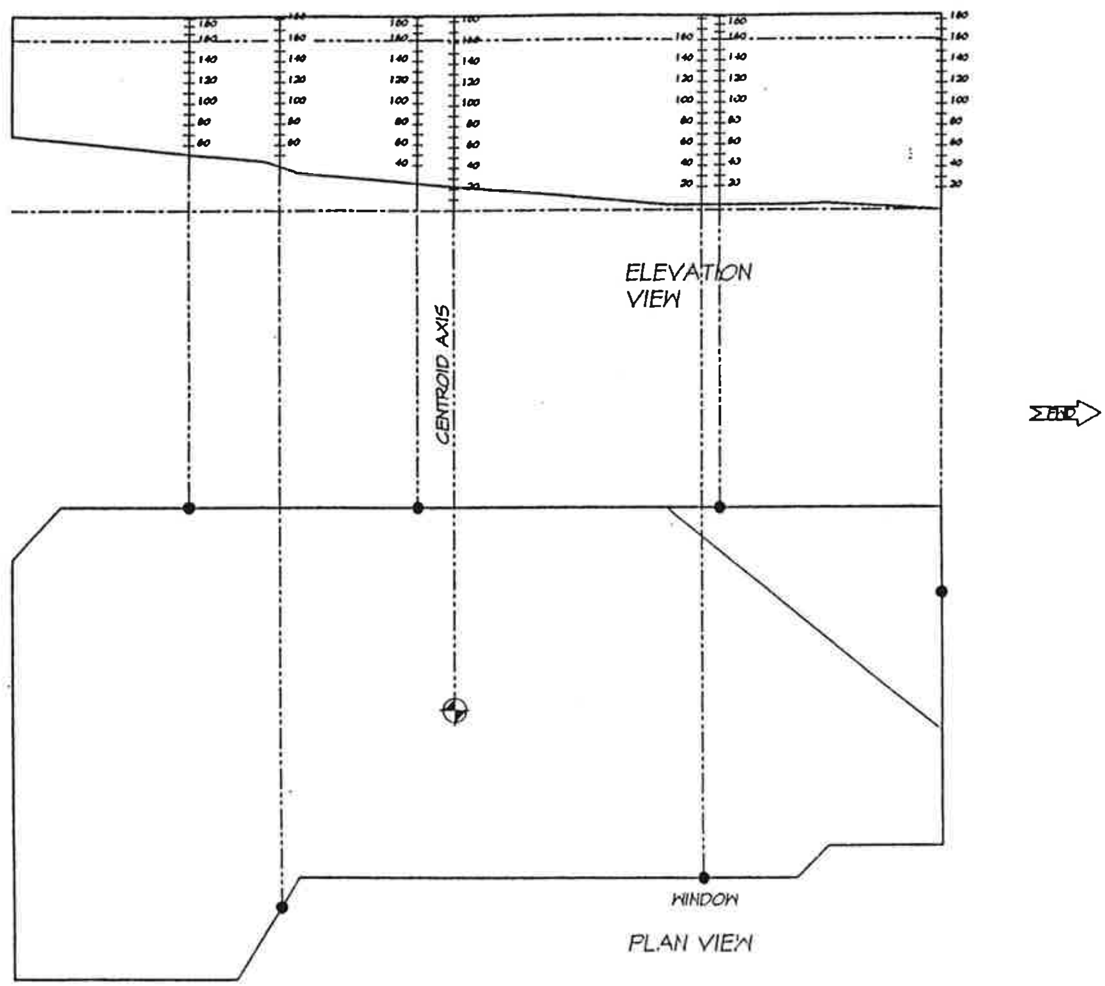



Figure 1. Upper port fish bin on the FT *American Triumph* showing location of measuring strips and viewing window (Drawing prepared by Jensen Maritime Consultants, 4241 21st Ave W, Seattle WA, 98199).

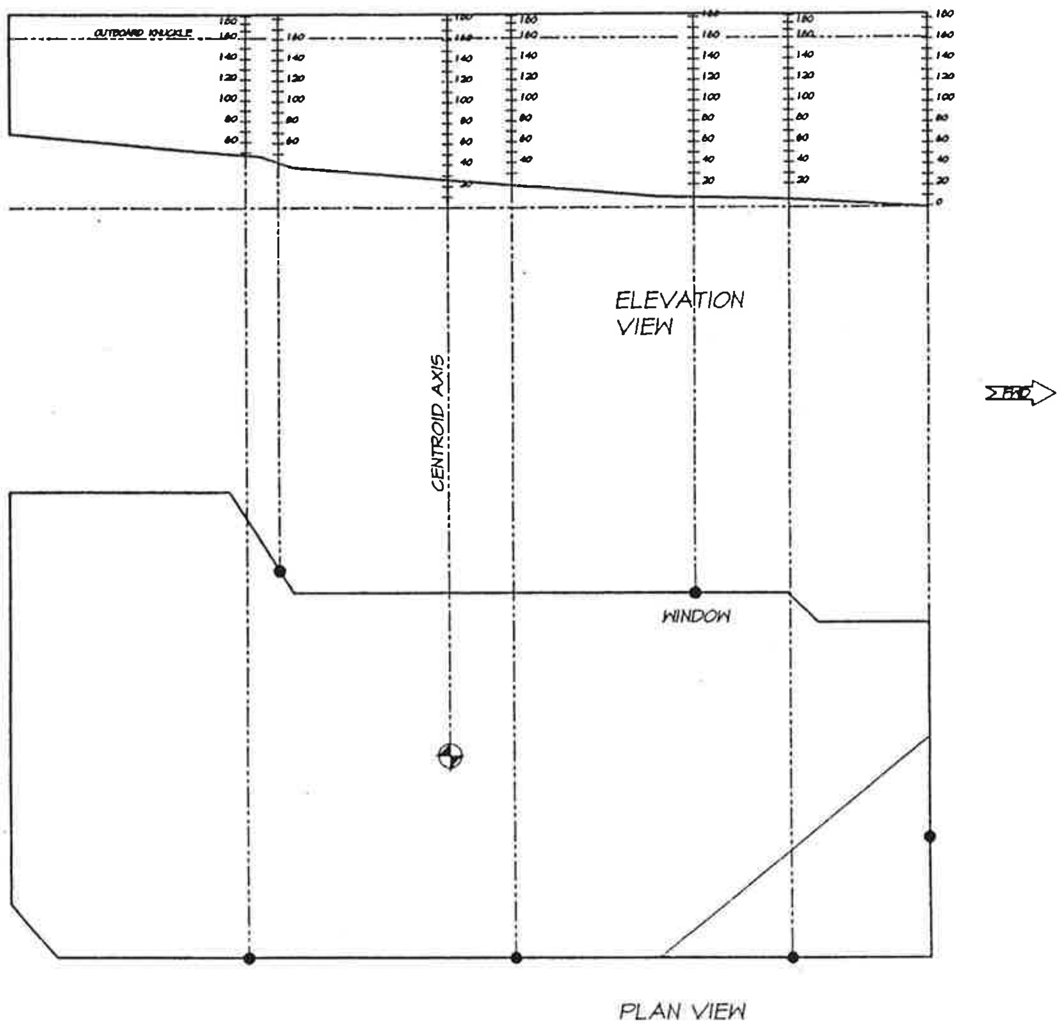



Figure 2. Upper starboard fish bin on the FT *American Triumph* showing location of measuring strips and viewing window (Drawing prepared by Jensen Maritime Consultants, 4241 21st Ave W, Seattle WA, 98199).

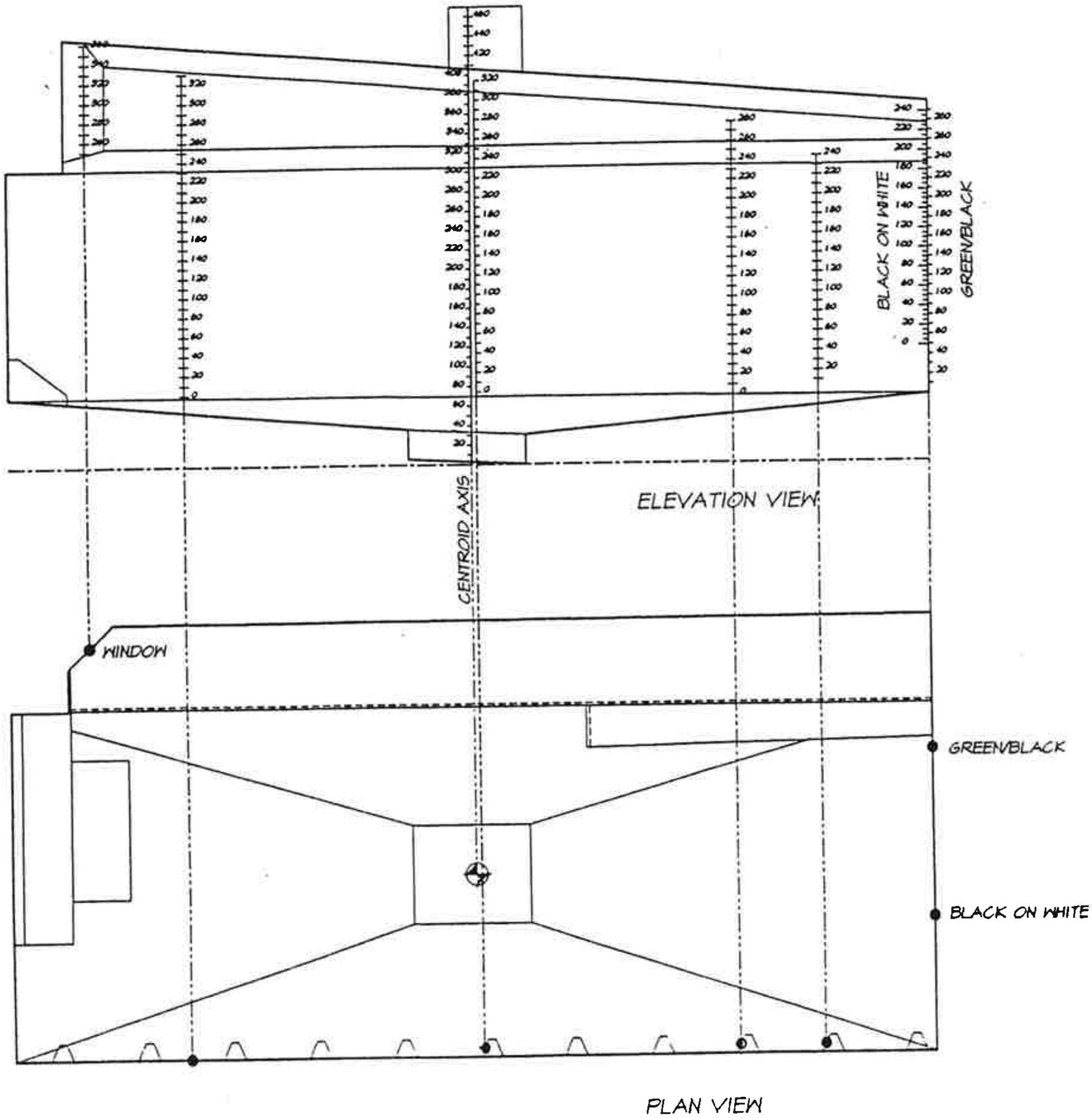



Figure 3. Lower port fish bin on the FT *American Triumph* showing location of measuring strips and viewing window (Drawing prepared by Jensen Maritime Consultants, 4241 21st Ave W, Seattle WA, 98199)

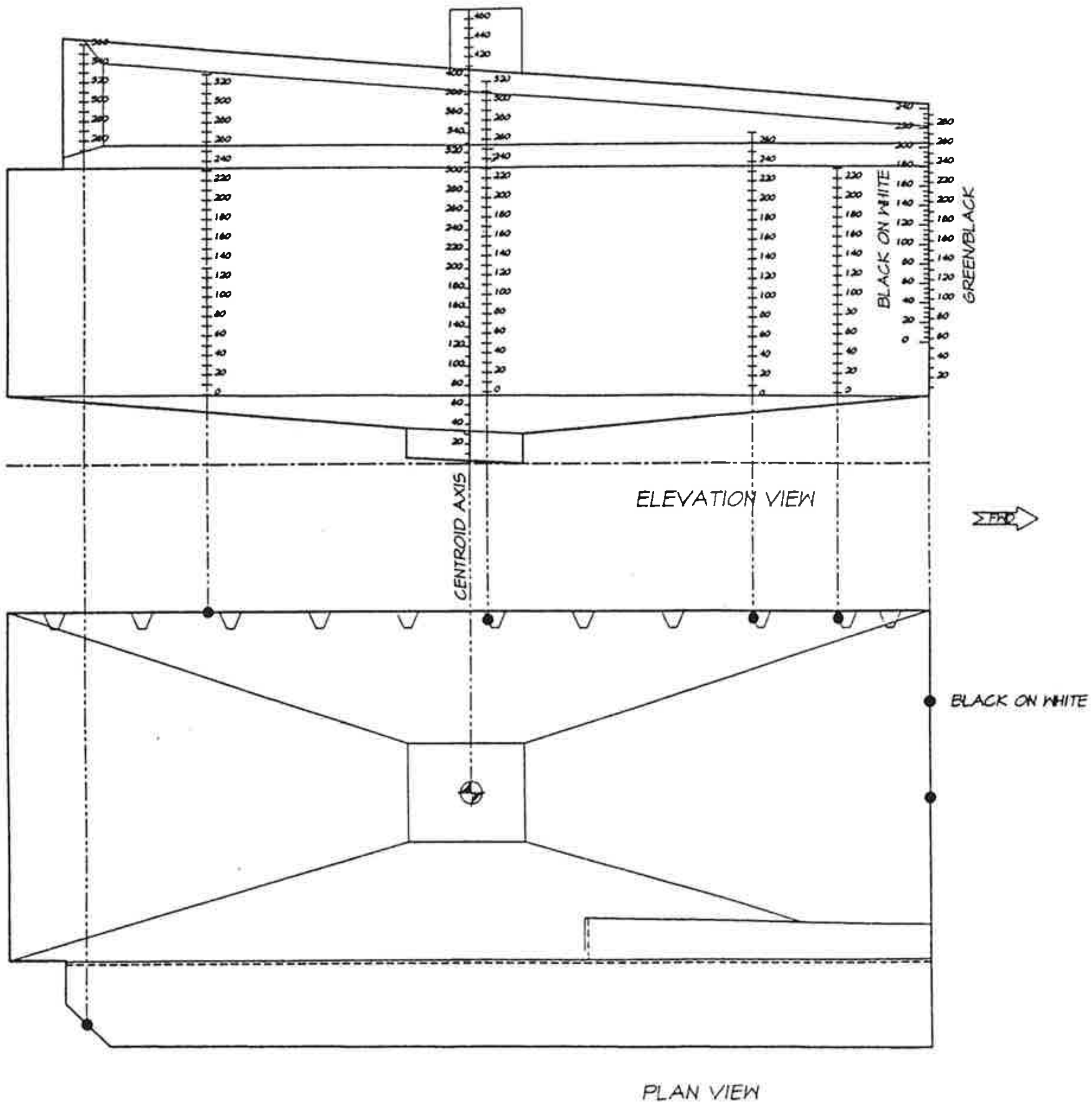



Figure 4. Lower starboard fish bin on the FT *American Triumph* showing location of measuring strips and viewing window (Drawing prepared by Jensen Maritime Consultants, 4241 21st Ave W, Seattle WA, 98199).

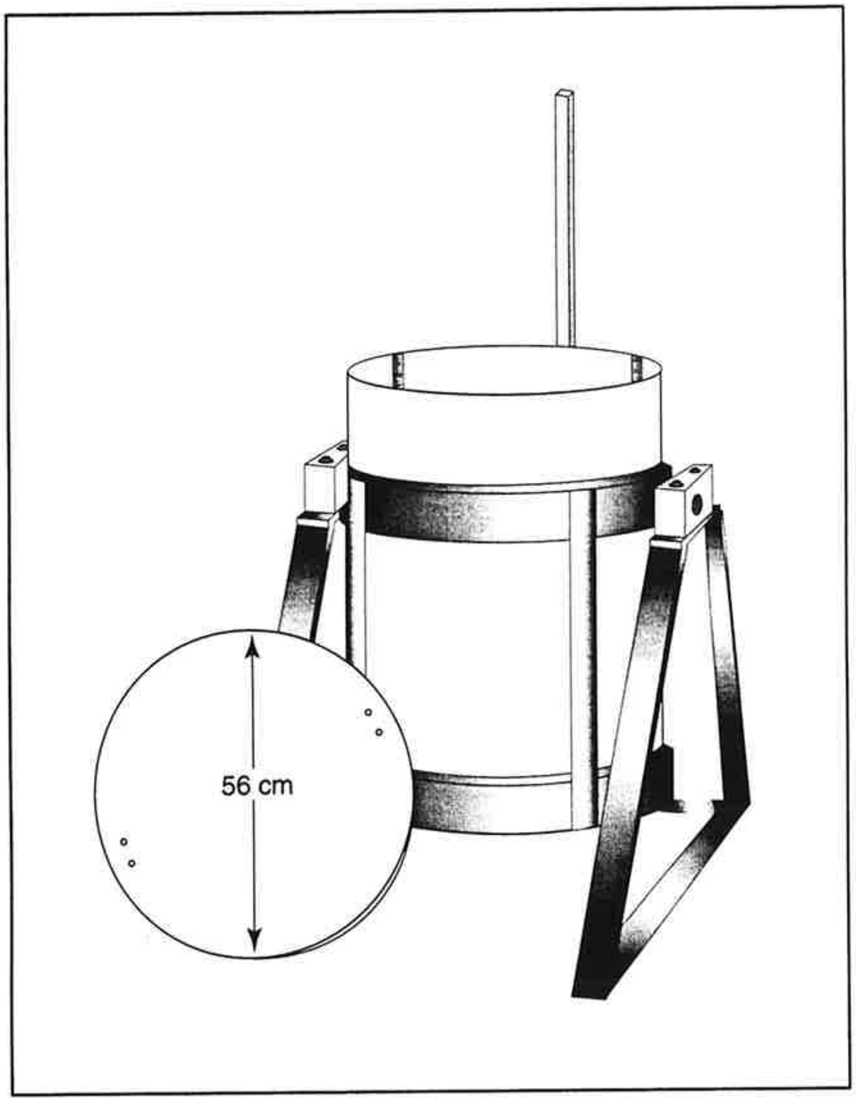



Figure 5. Prototype density sampler used during the research charter of the FT *American Triumph.*

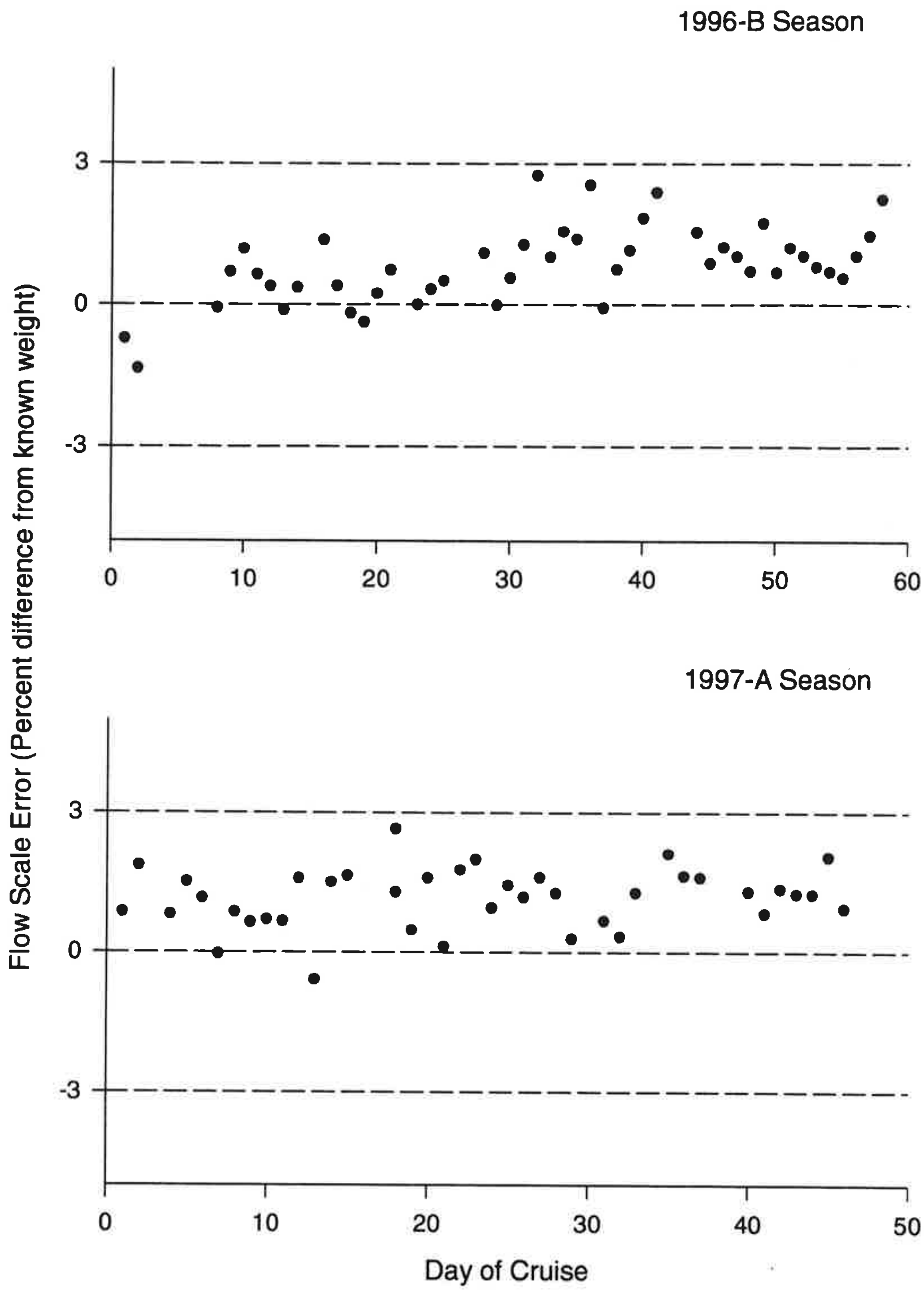



Figure 6. Flow scale error from materials tests by day of cruise for 1996-B and 1997-A seasons.

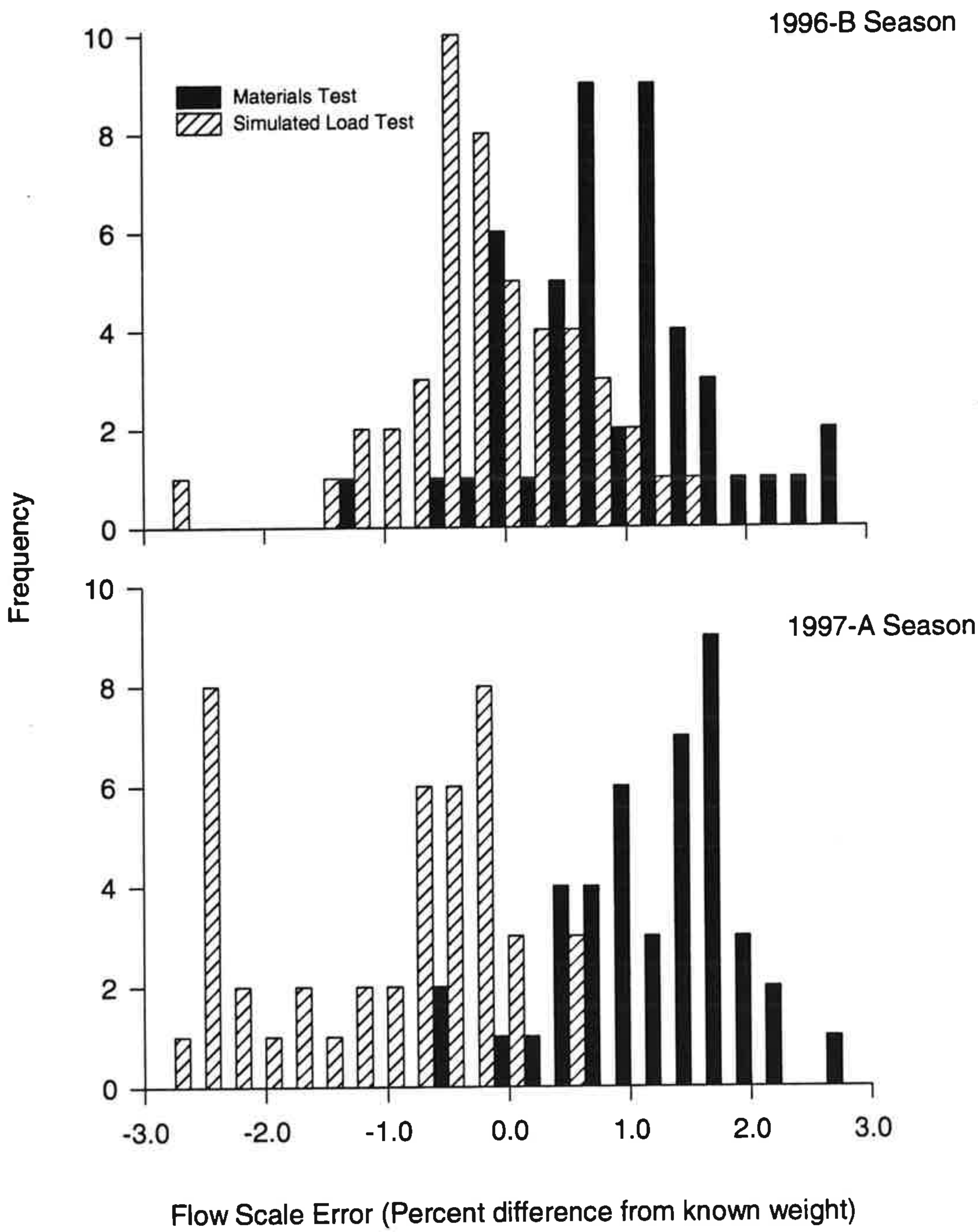



Figure 7. Scale error distributions for 1996-B and 1997-A season materials tests and simulated load tests. Plotted simulated load tests were run for 15 revolutions in 1996-B season and 30 revolutions in 1997-A season, and may not be directly comparable.

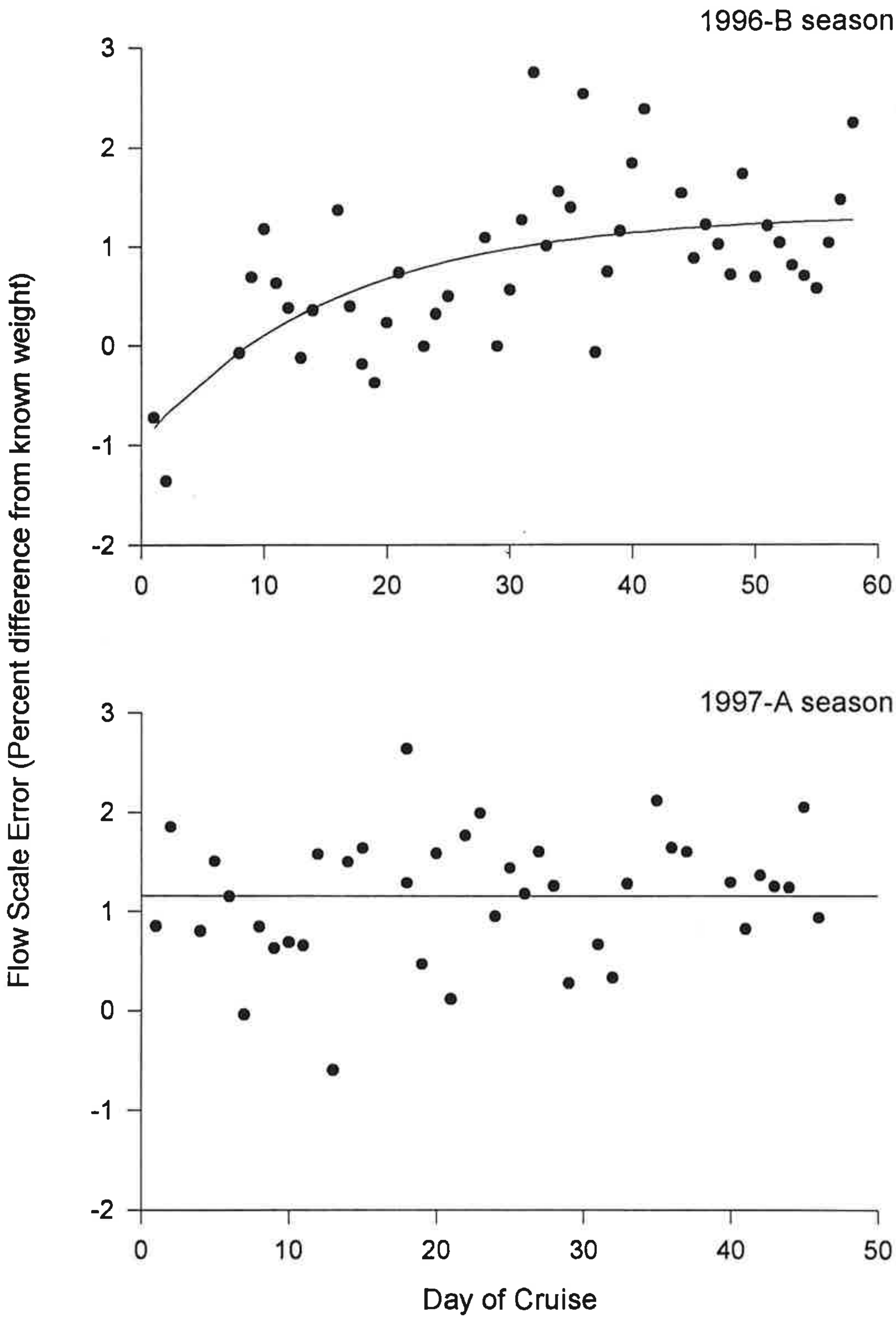



Figure 8. Time trends in mean scale error (materials tests) used for scale weight correction factors for the 1996-B and 1997-A season.

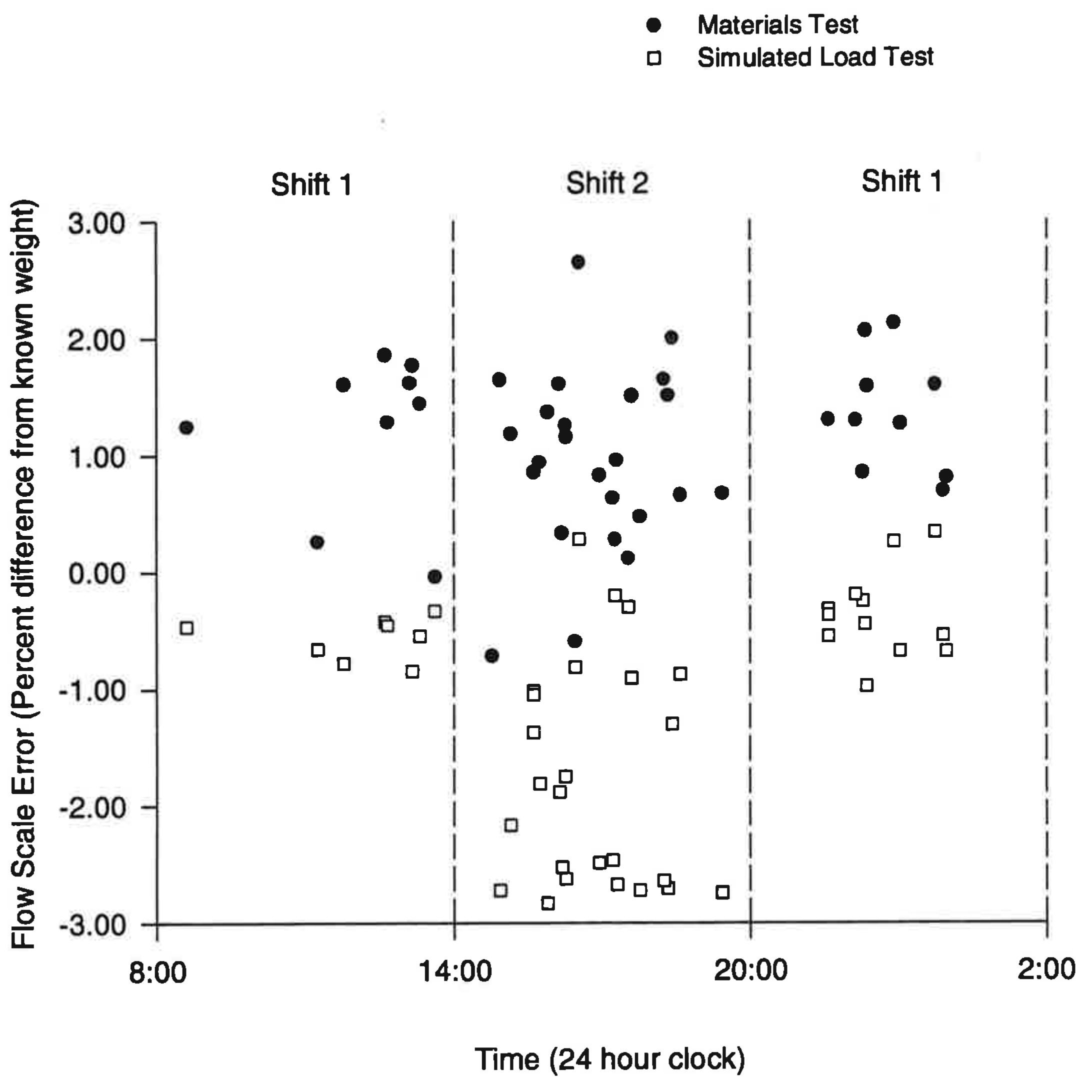



Figure 9. 1997-A season flow scale error distributions by time of day. Factory Shift 1 personnel worked 0800 - 1400 and 2000 to 0200; Shift 2 personnel worked 1400 - 2000 and 0200 to 0800. No scale tests were conducted between 0200 and 0800.

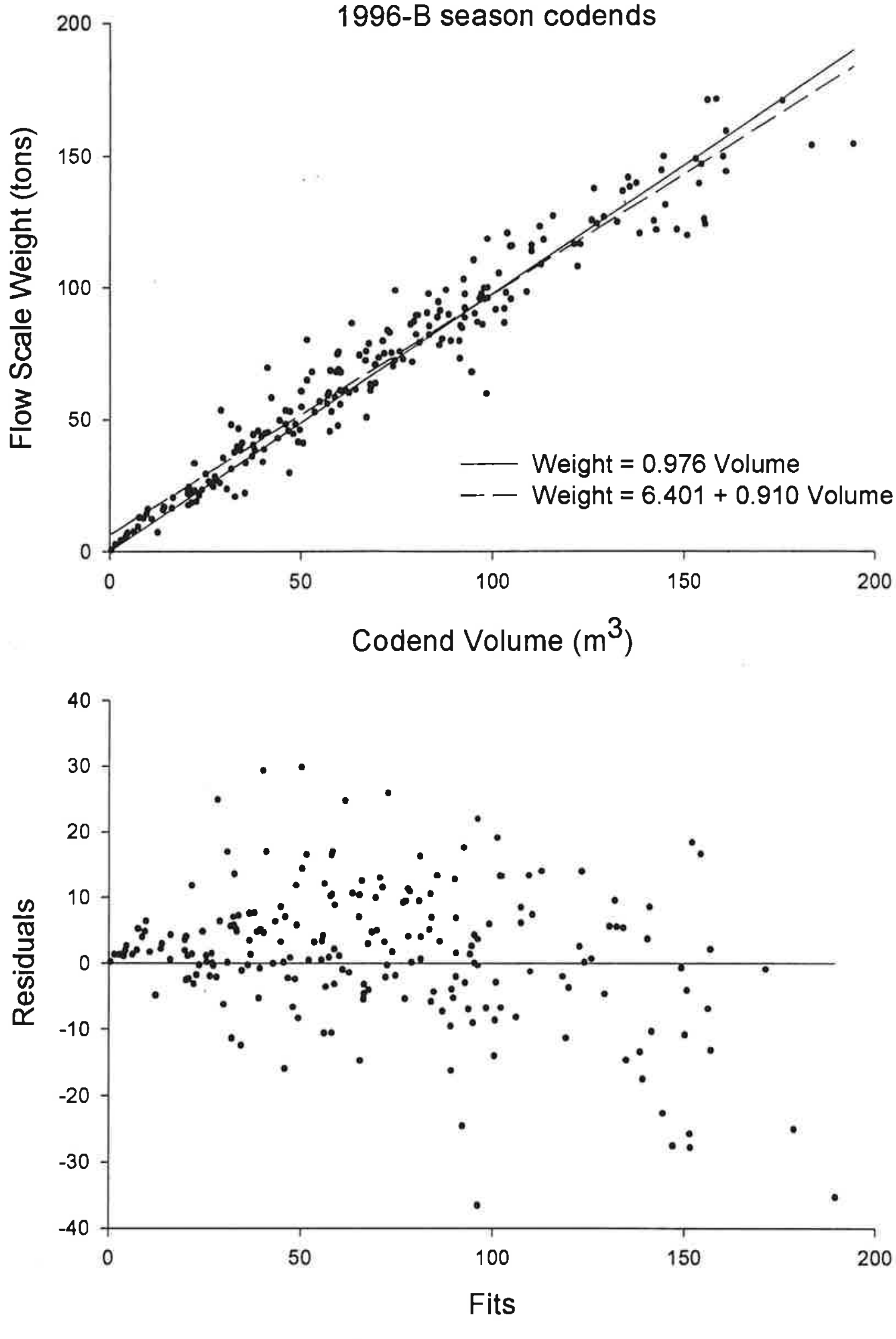
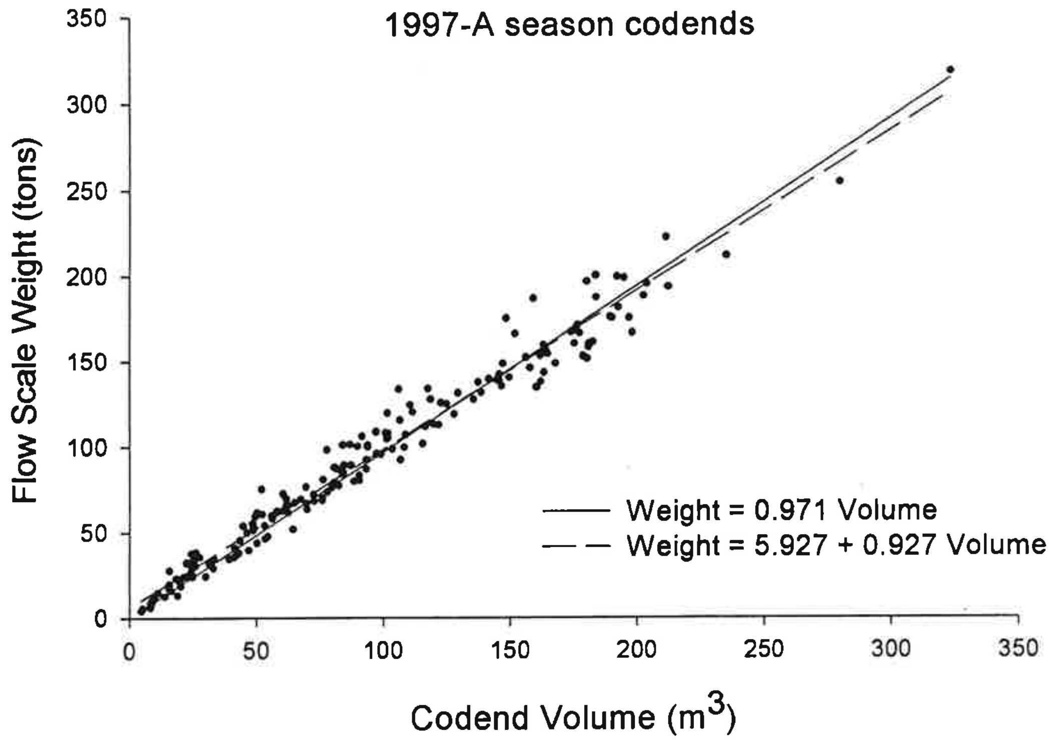



Figure 10. Least squares linear regressions of 1996-B season codend weight on volume, and zero intercept model residuals.



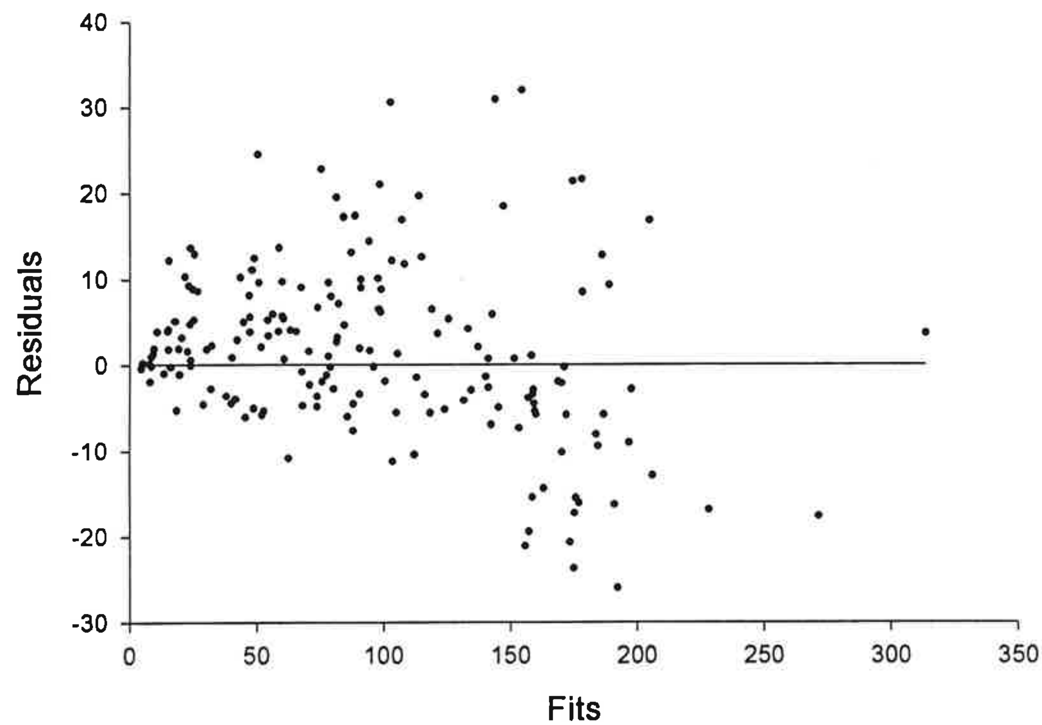




Figure 11. Least squares linear regressions of 1997-A season codend weight on volume, and zero intercept model residuals.

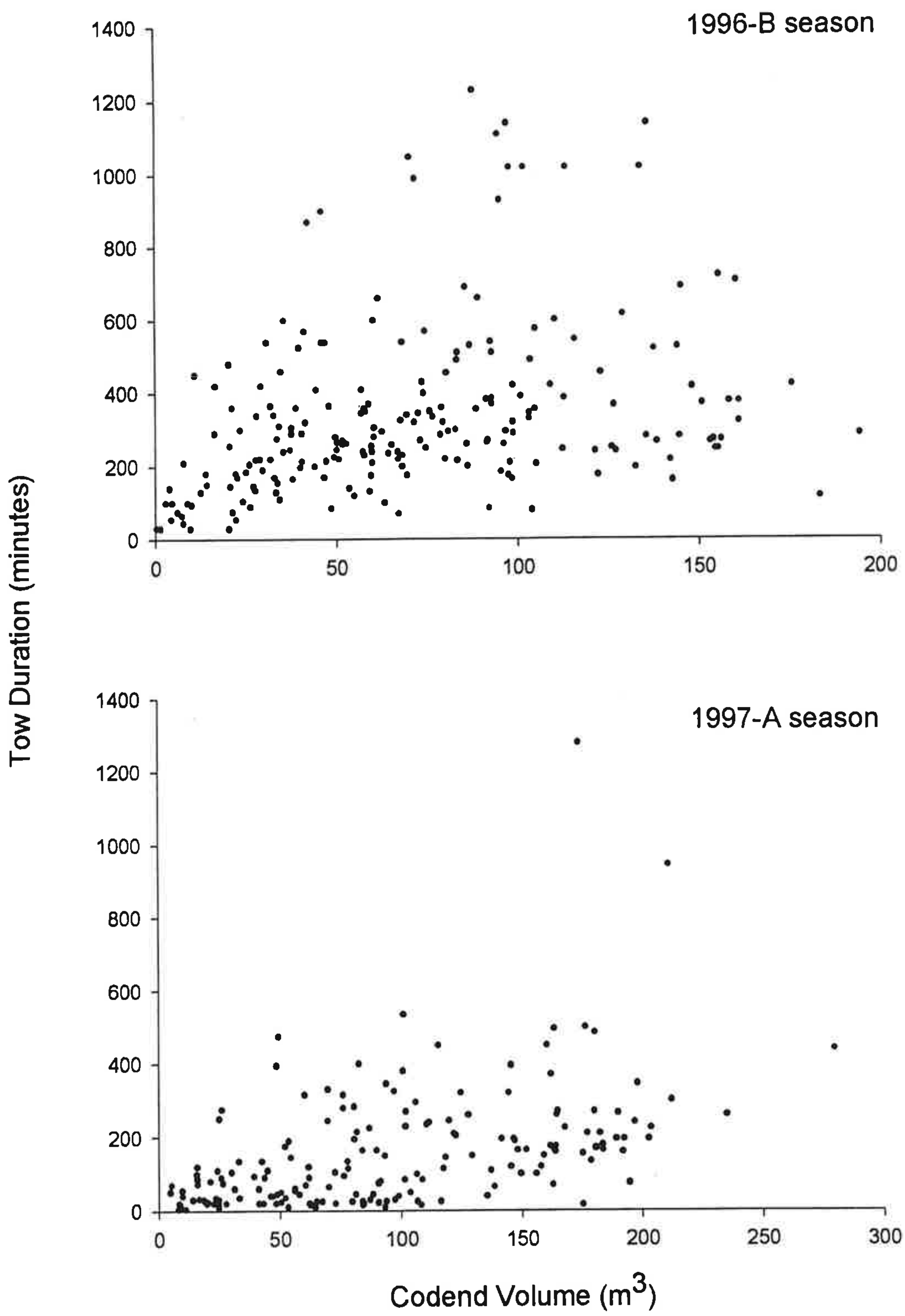
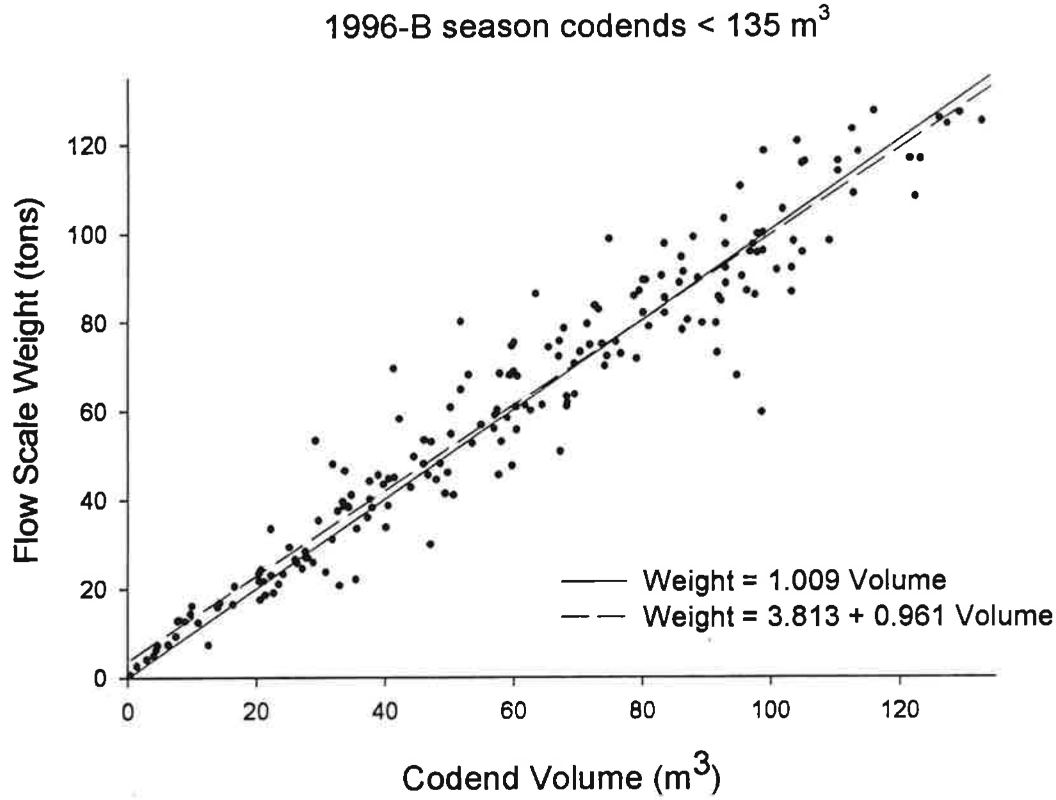



Figure 12. Relationship of tow duration with codend volume during 1996-B and 1997-A seasons.



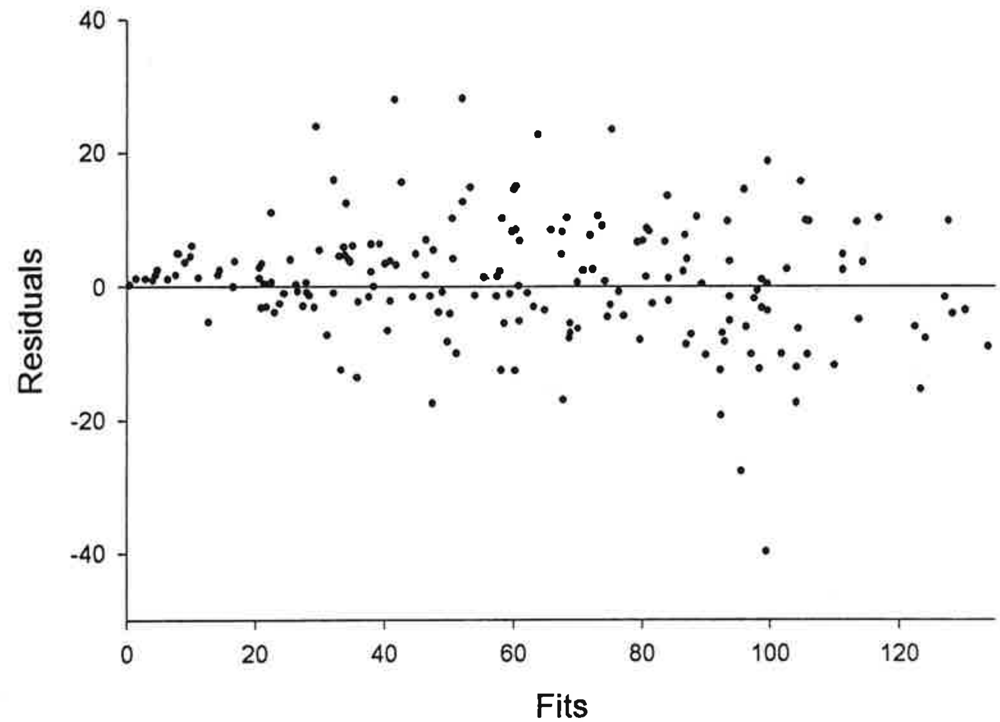




Figure 13. Least squares linear regressions of 1996-B season codend weight on volume for codends fitting in the trawl alley, and zero intercept model residuals.

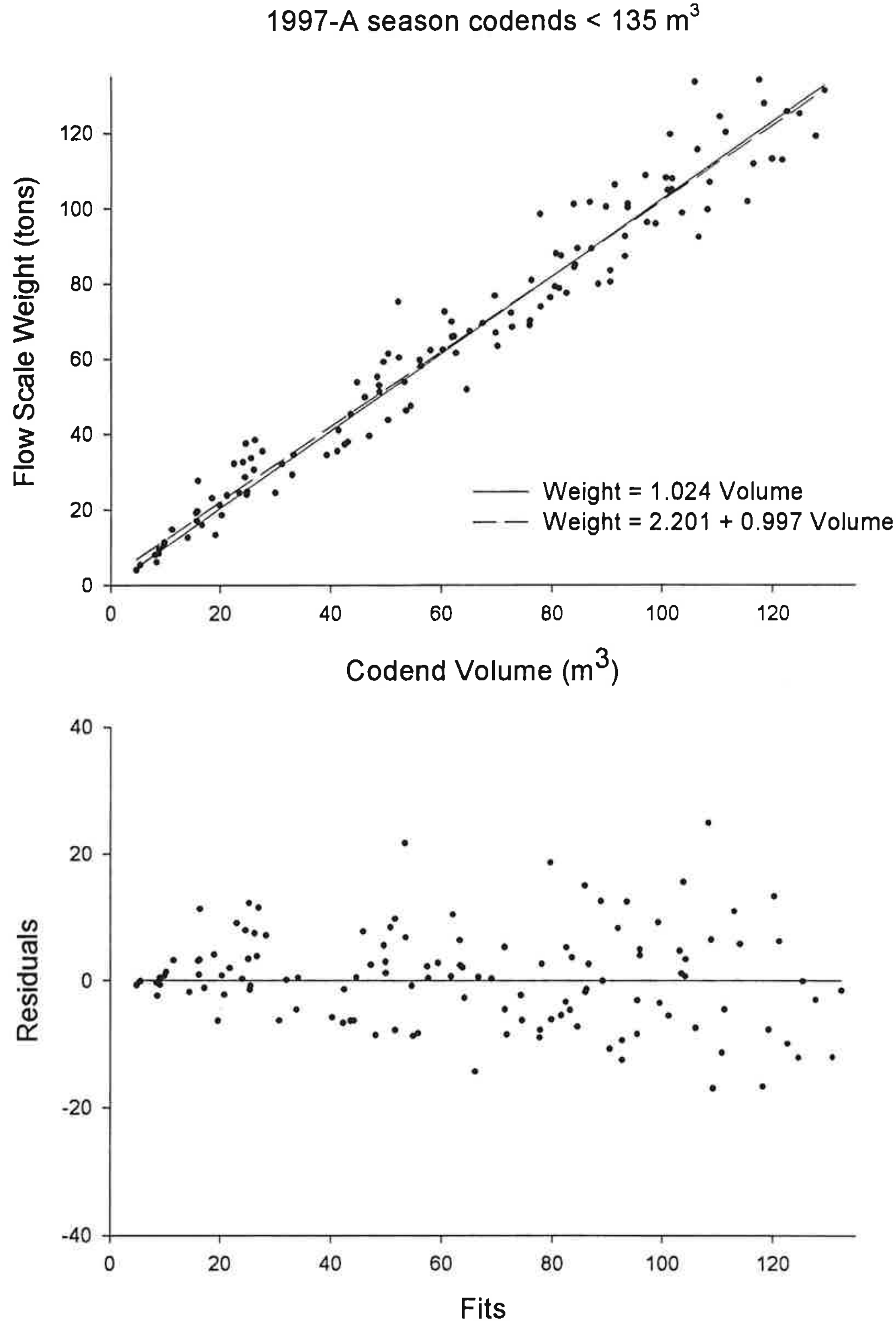



Figure 14. Least squares linear regressions of 1997-A season codend weight on volume, and zero intercept model residuals for codends fitting in the trawl alley.

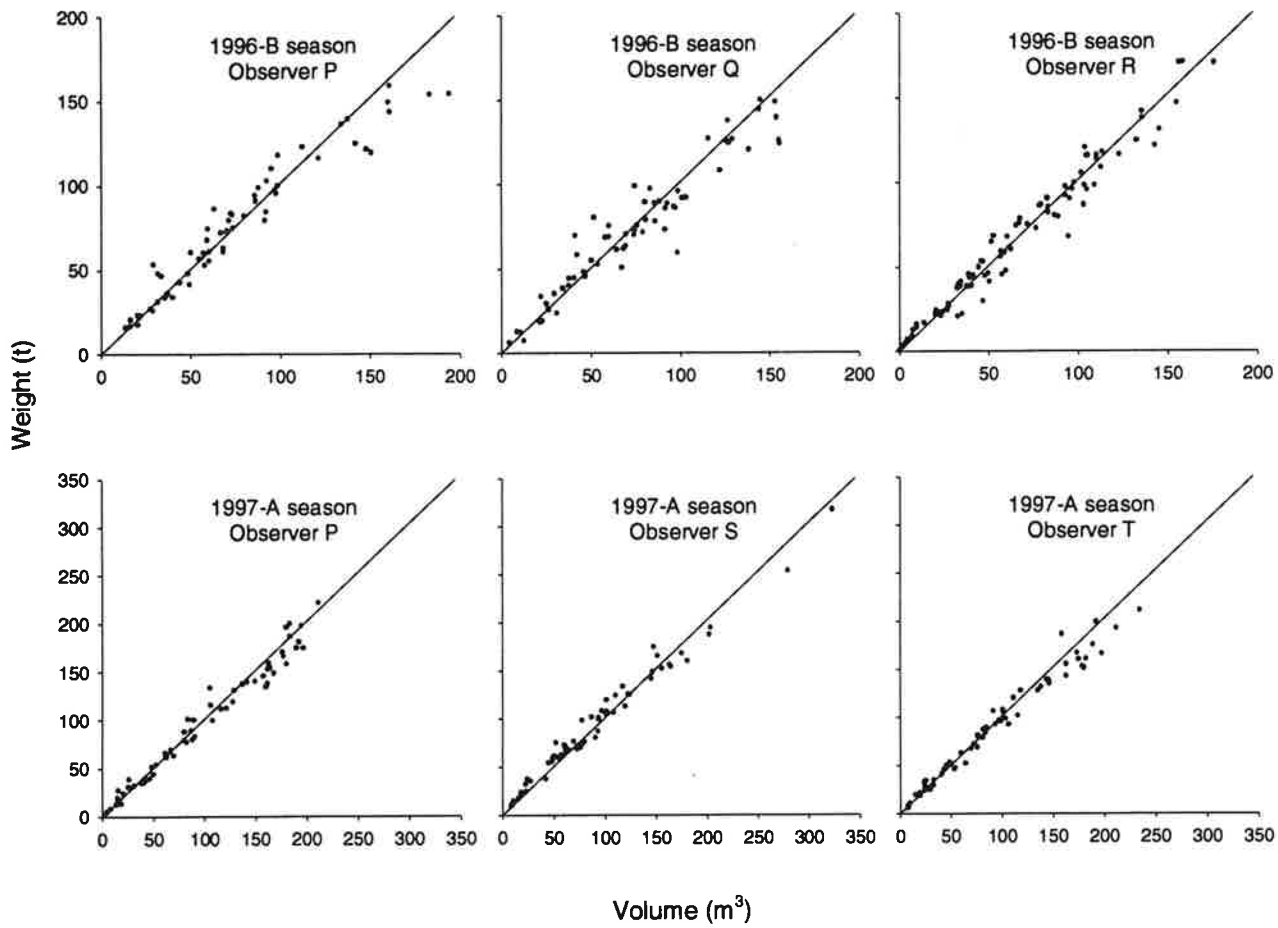
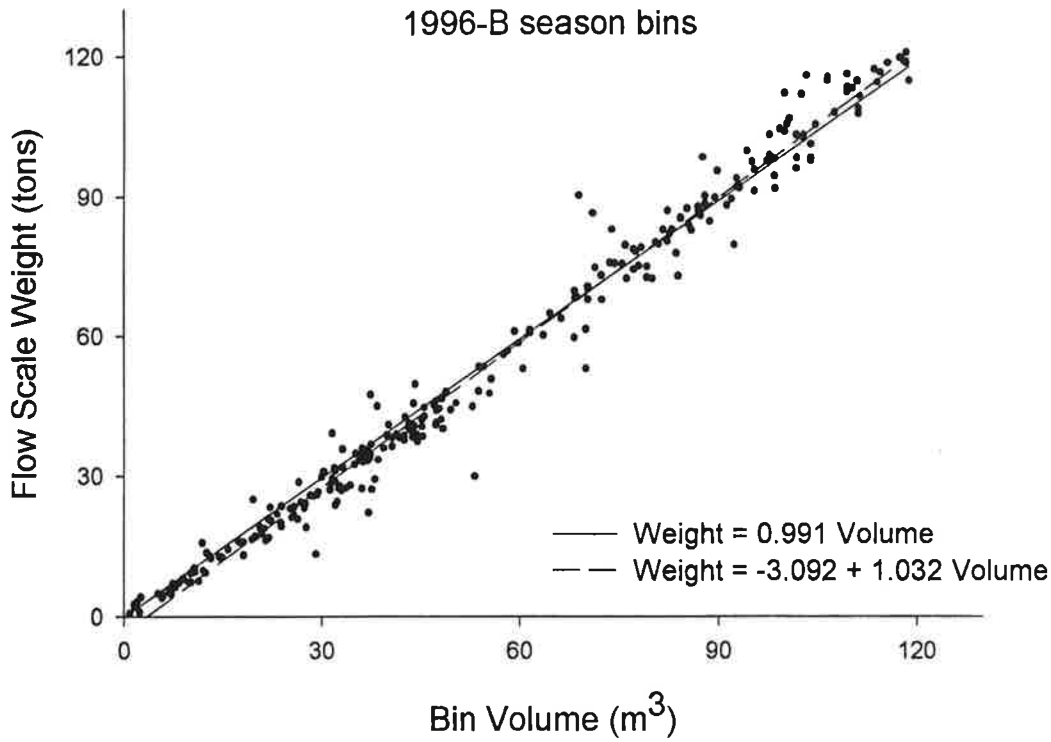



Figure 15. Comparison of individual observer codend volume-weight relationships for 1996-B and 1997-A seasons. In each plot, the line represents the seasons combined zero-intercept least squares regression of weight on volume for codends fitting in the trawl alley. (Slope of the regression line =1.015.)



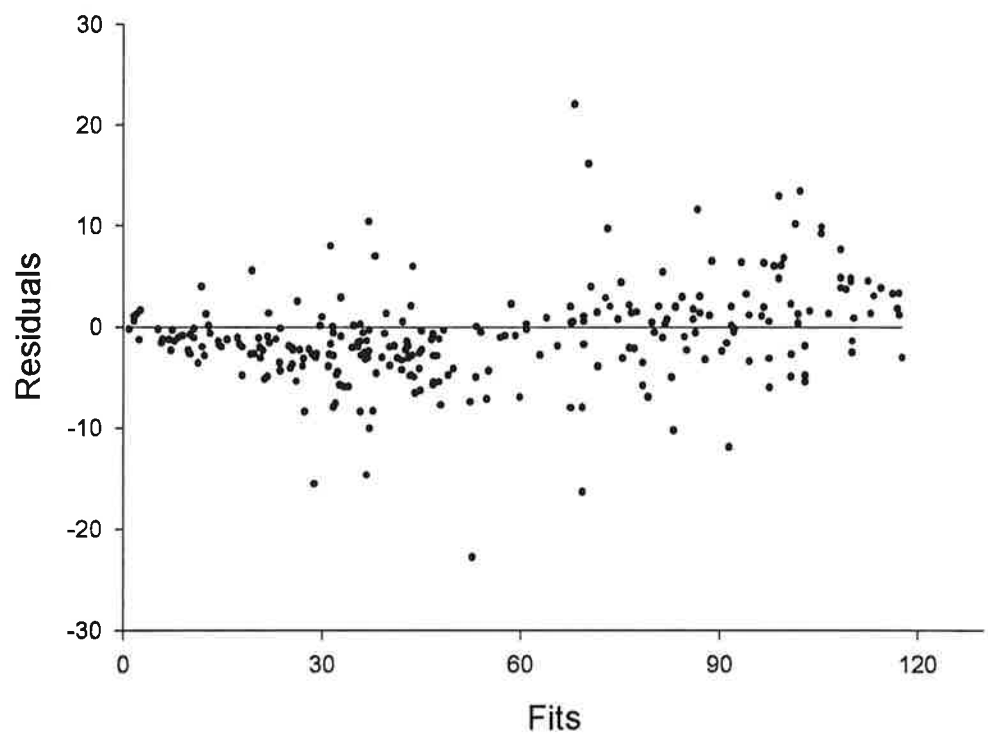




Figure 16. Least squares linear regressions of 1996-B season bin weight on volume, and zero intercept model residuals.

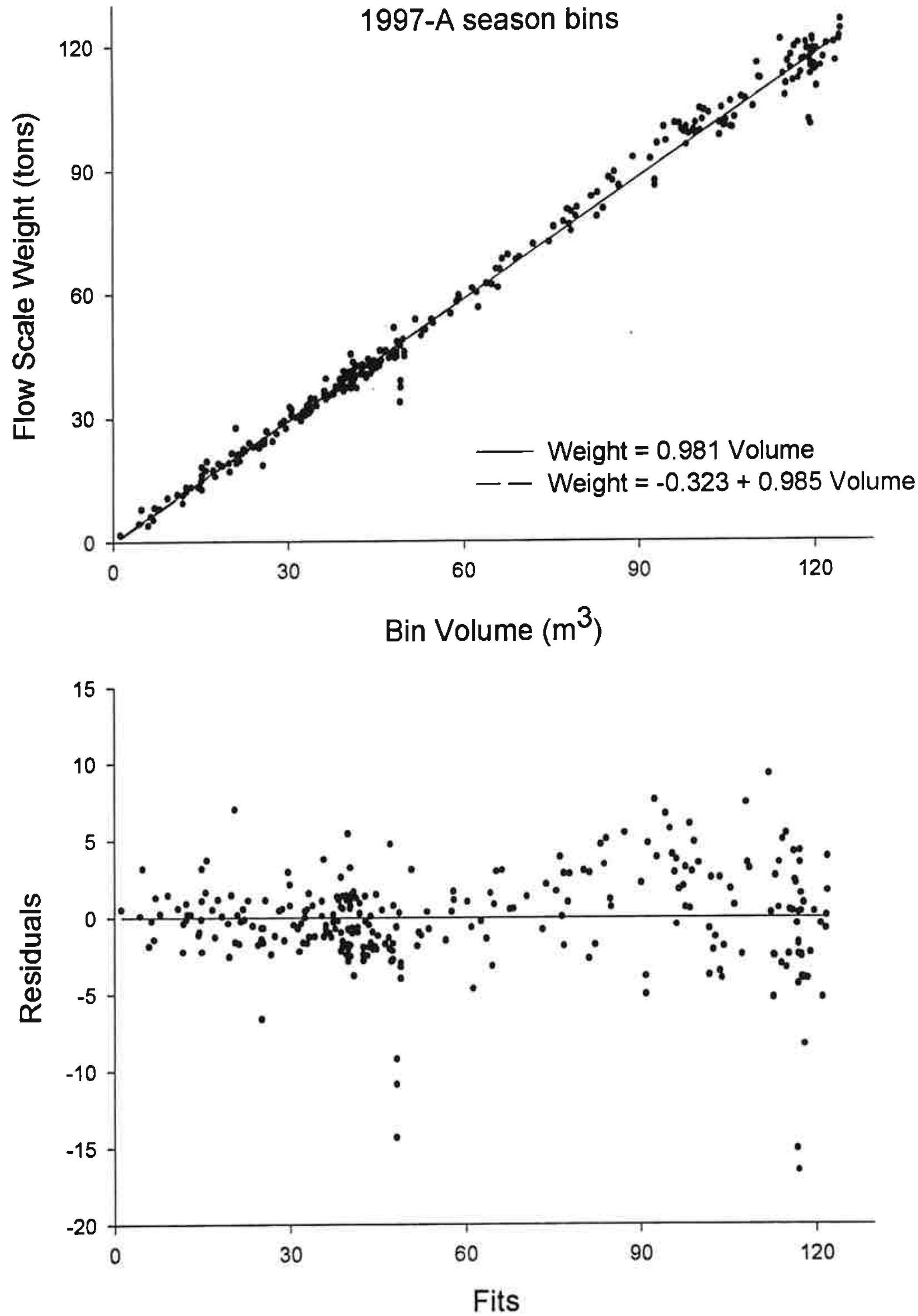



Figure 17. Least squares linear regressions of 1997-A season bin weight on volume, and zero intercept model residuals. Regression lines overlap and are indistinguishable.

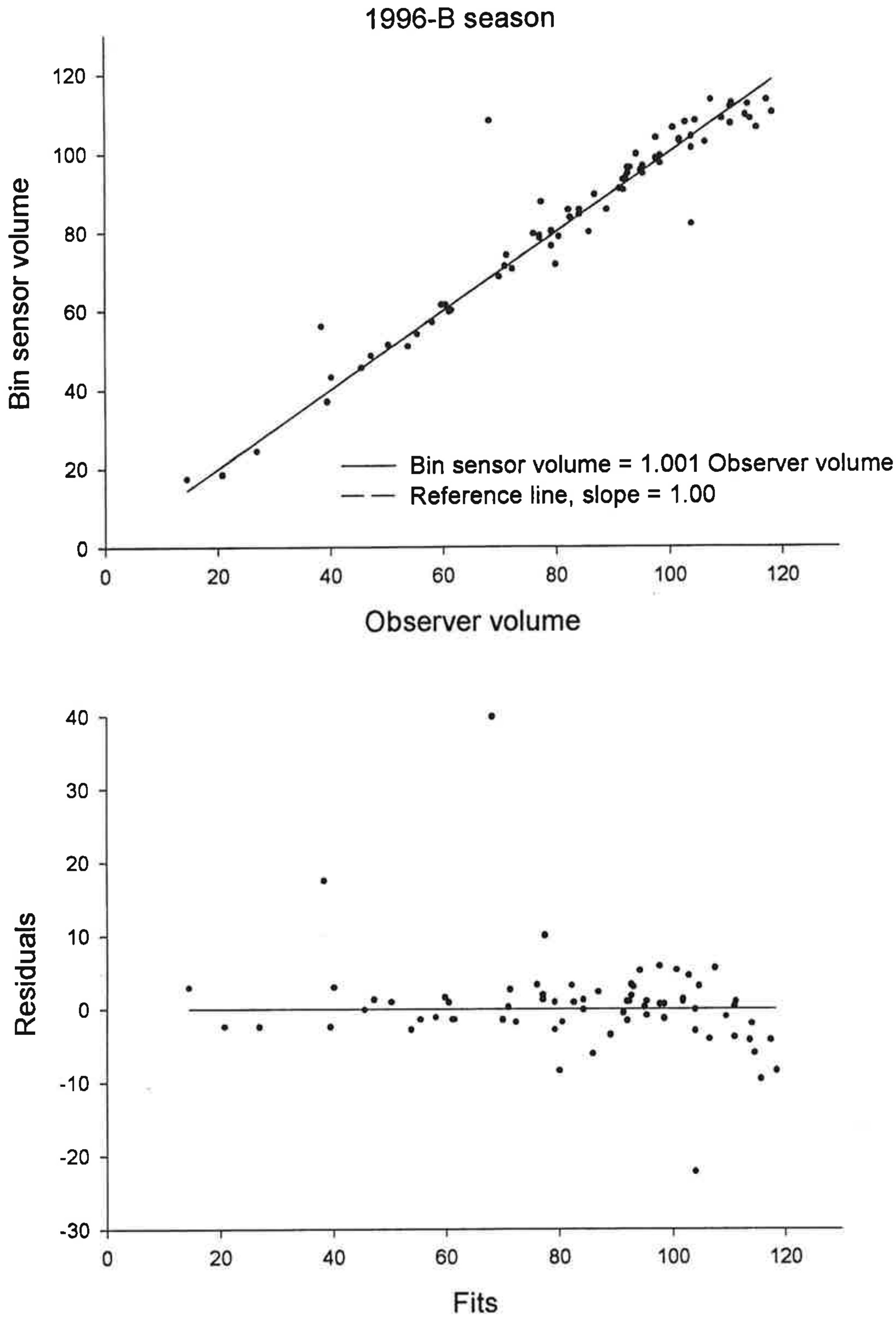



Figure 18. Comparison of 1996-B season bin sensor volumes with observer (visual) bin volume estimates. The regression and reference lines are both shown, but overlap.

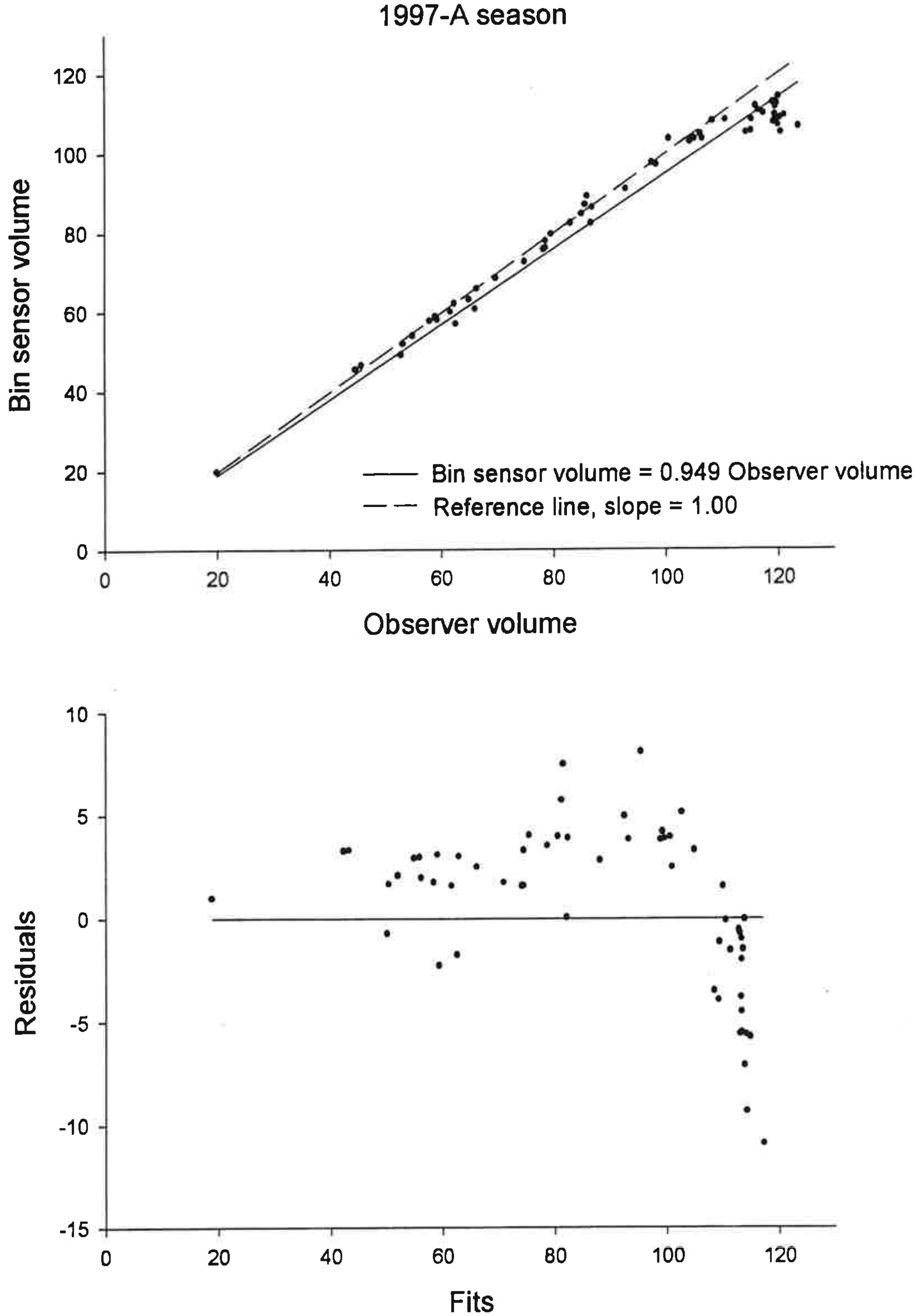



Figure 19. Comparison of 1997-A season bin sensor volumes with observer (visual) bin volume estimates.

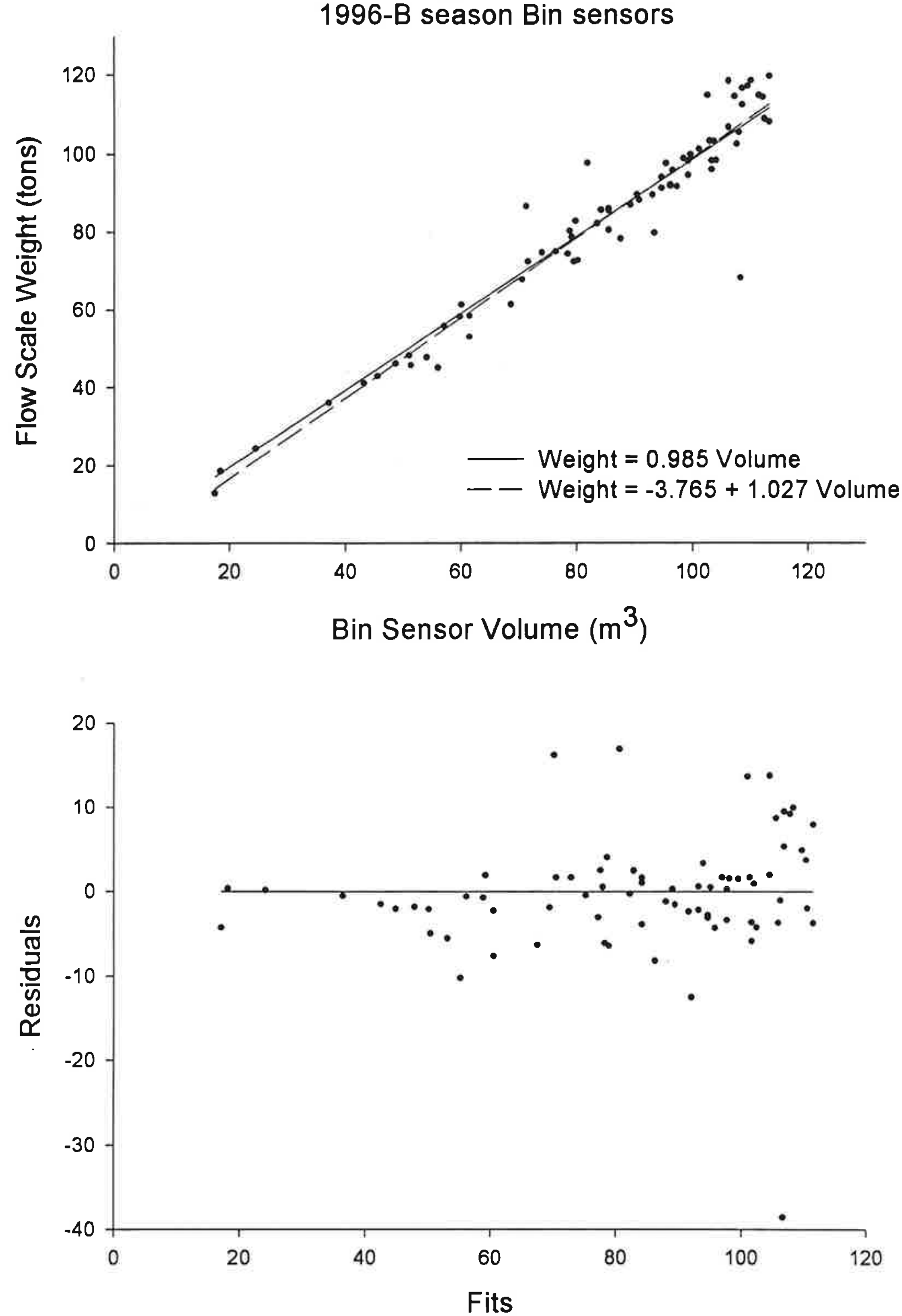



Figure 20. Least squares linear regressions of 1996-B season bin weight on bin sensor volume, and zero intercept model residuals.

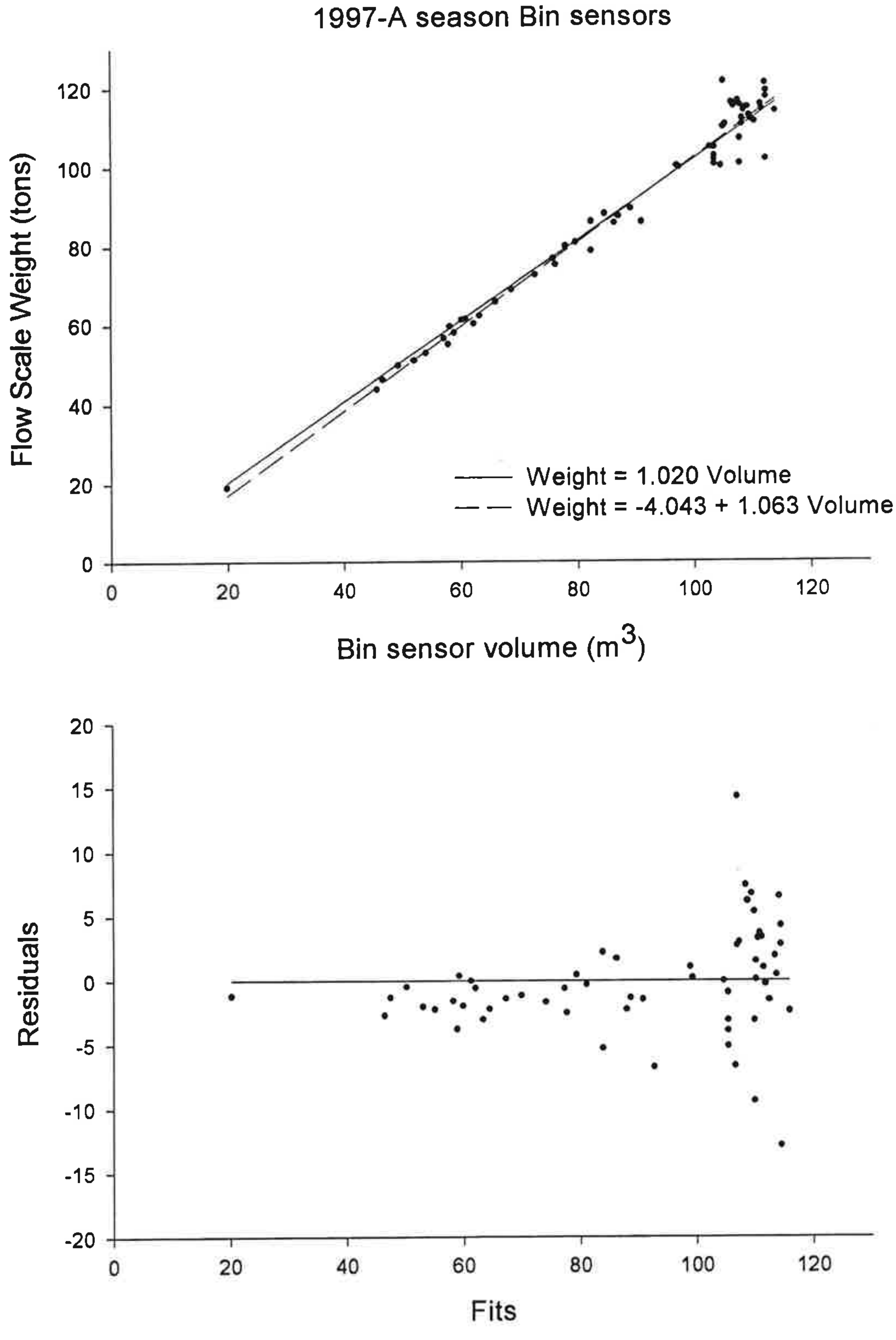



Figure 21. Least squares linear regressions of 1997-A season bin weight on bin sensor volume, and zero intercept model residuals.

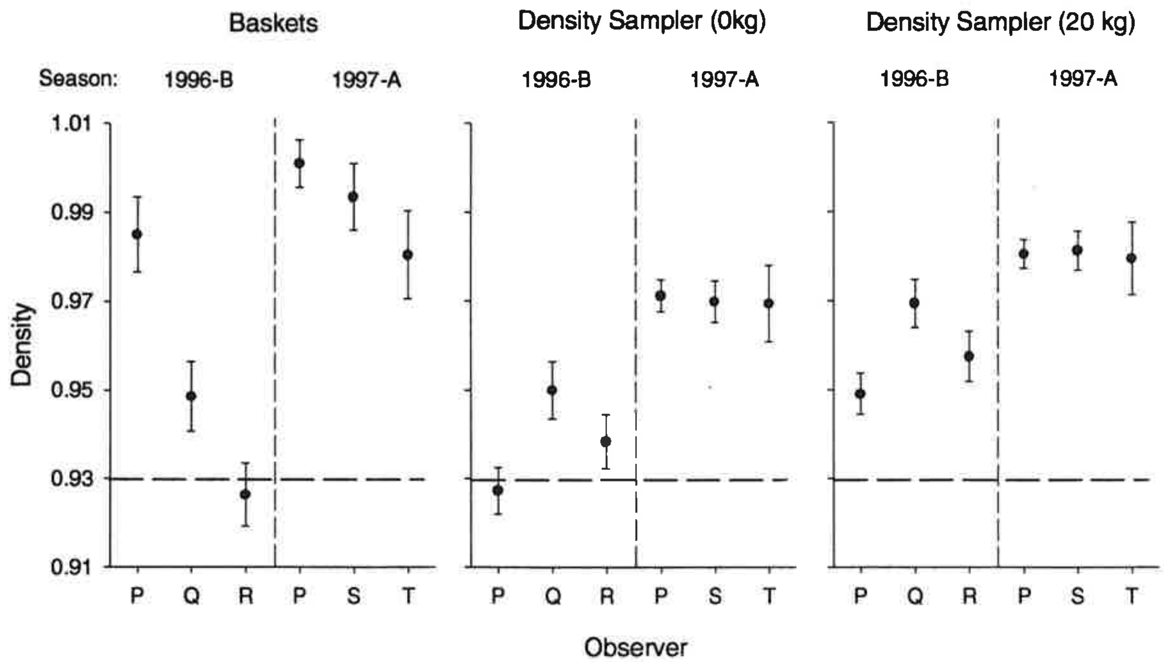



Figure 22. Comparison of individual observer density estimates using baskets, the density sampler with 0 kg on the lid, and the density sampler with 20 kg on the lid. 1996-B and 1997-A seasons are separated by dashed vertical lines. Observer P was on board in both seasons.

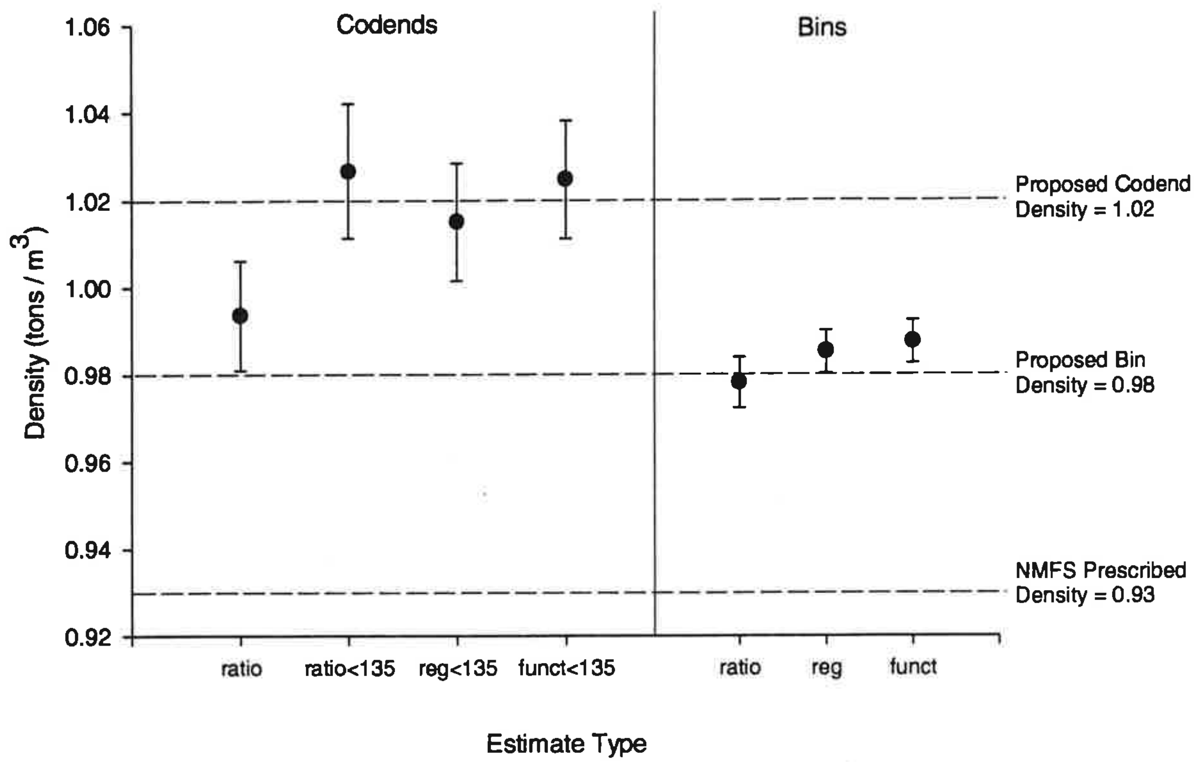



Figure 23. Comparison of seasons combined*in situ* density estimates. Ratio = ratio estimate for all codends or bins, ratio<135 = ratio estimate for codends fitting in the trawl alley, reg<135 = zero intercept least squares regression estimate for codends fitting in the trawl alley, funct<135 = zero intercept functional regression estimate for codends fitting in the trawl alley, reg = zero intercept least squares regression estimate for all bins, funct = zero intercept functional regression estimate for all bins.

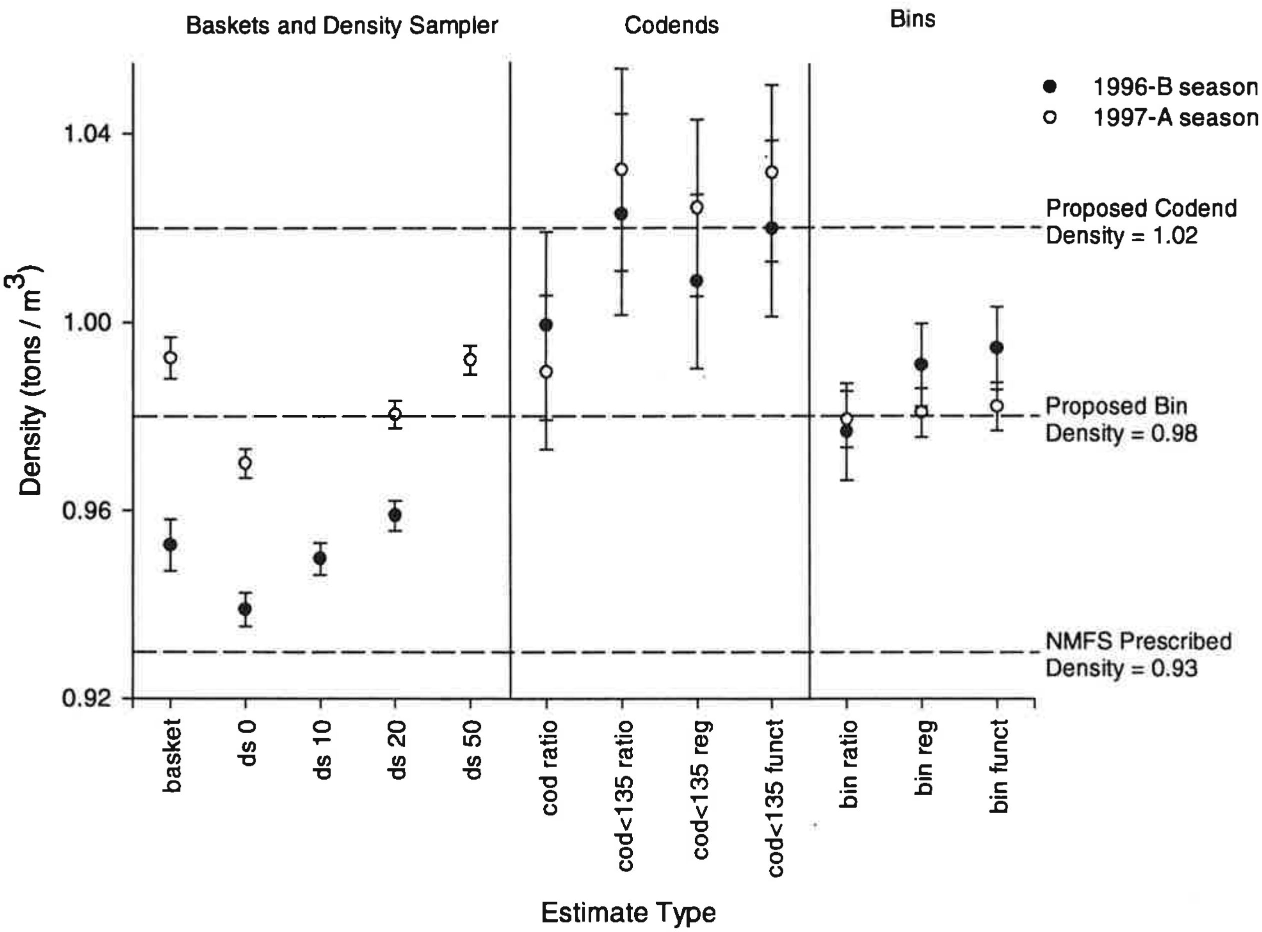



Figure 24. Comparison of density estimates for all estimate types and seasons. Basket = basket density, ds0 = density sampler with no weight on lid, ds10 = density sampler with 10 kg on lid, ds20 = density sampler with 20 kg on lid, ds50 = density sampler with 50 kg on lid, cod ratio = ratio estimate for all codends, cod<135 ratio = ratio estimate for codends fitting in the trawl alley, cod<135 reg = zero intercept least squares regression estimate for codends fitting in the trawl alley, cod<135 funct = zero intercept functional regression estimate for codends fitting in the trawl alley, bin ratio = ratio estimate for all bins, bin reg = zero intercept least squares regression estimate for all bins, bin funct = zero intercept functional regression estimate for all bins.

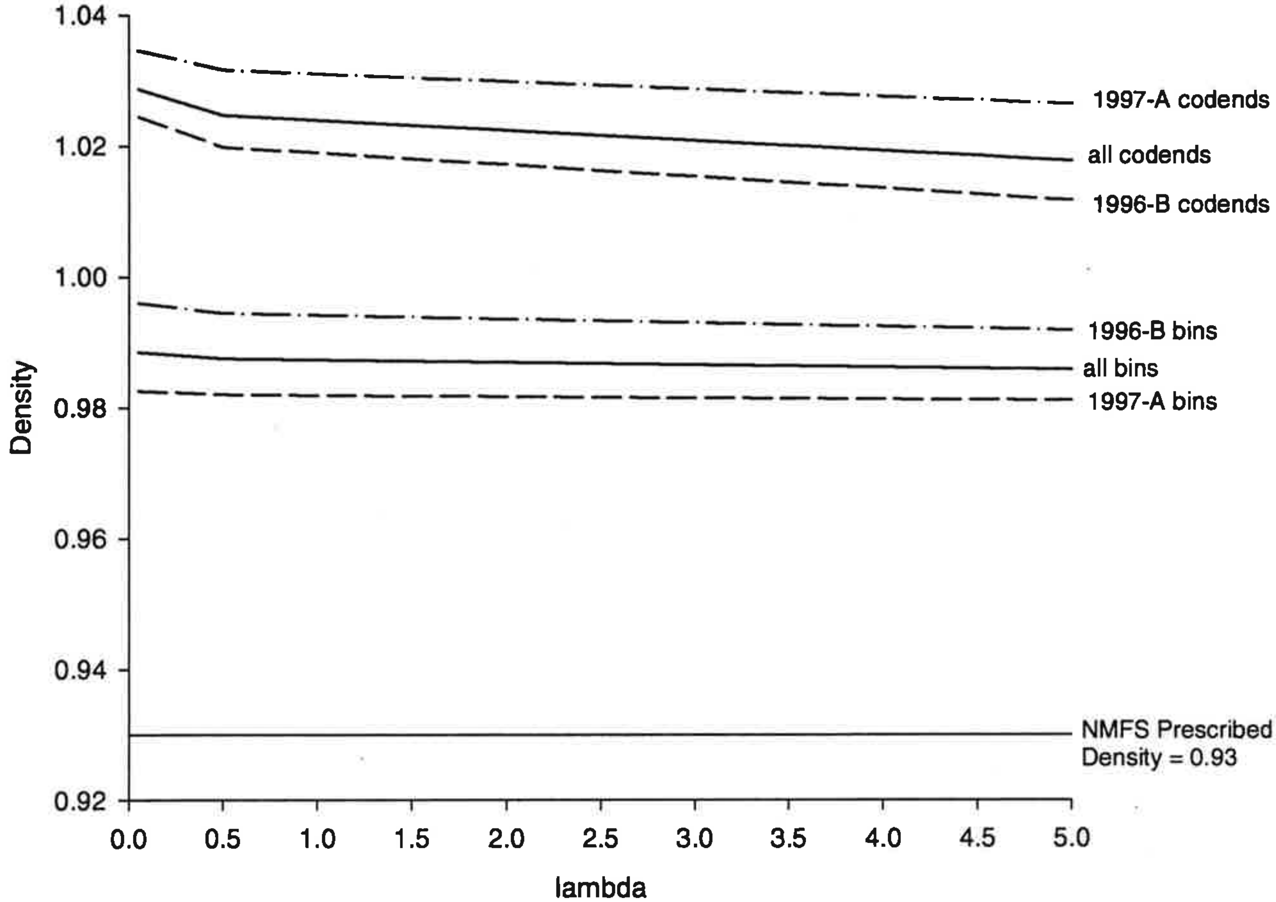



Figure 25. Change in functional regression estimates of *in situ* density with variation of lambda, the ratio of weight measurement error to volume measurement error. As lambda increases along the x-axis, the volume measurement error becomes very small in comparison to the weight measurement error. At high values of lambda, functional regression approaches the assumptions (and therefore the results) of least squares regression.

**Appendix 1: The Beaufort Scale.**

| Beaufort Number | Description | Wind Speed (knots) | Sea Surface Conditions | Wave Height (ft) |
|---|---|---|---|---|
| 0 | Calm | <1 | Sea smooth and mirror-like. | 0 |
| 1 | Light air | 1-3 | Scale-like ripples without foam crests. | 0 |
| 2 | Light breeze | 4-6 | Small wavelets; crests have a glassy appearance but do not break. | 2 |
| 3 | Gentle breeze | 7-10 | Large wavelets; crests begin to break; scattered whitecaps. | 3 |
| 4 | Moderate breeze | 11-16 | Small waves, becoming longer; fairly frequent whitecaps. | 4 |
| 5 | Fresh breeze | 17-21 | Moderate waves taking longer form; many whitecaps and chance of some spray. | 6 |
| 6 | Strong breeze | 22-27 | Large waves forming; whitecaps extensive everywhere and spray probable. | 10 |
| 7 | Near gale | 28-33 | Sea heaps up and white foam from breaking waves begins to be blown in streaks; spindrift begins. | 14 |
| 8 | Gale | 34-40 | Moderately high waves of greater length; edges of crests break into spindrift; foam blown in well-marked streaks along the direction of the wind. | 18 |
| 9 | Strong gale | 41-47 | High waves; dense streaks of foam; sea begins to roll; spray may affect visibility. | 23 |
| 10 | Storm | 48-55 | Very high waves with overhanging crests; sea surface takes on white appearance as foam in great patches is blown in very dense streaks; rolling of the sea is heavy and visibility reduced. | 29 |
| 11 | Violent storm | 56-64 | Exceptionally high waves that may obscure small and medium sized ships; sea covered with long white patches of foam; visibility further reduced. | 37 |
| 12 | Hurricane | >64 | Air filled with foam and spray; sea completely white with driving spray; visibility extremely poor. | 45 |

## Appendix 2: Observer Estimates of Total Catch Weight On Trawlers (from Manual for Biologists aboard Domestic Groundfish Vessels)

Objectives:

Make an **independent, non-biased and substantiated** estimate of total catch weight for as many tows as possible. Only observers on trawlers which pump the fish out of the net as it lies in the water are not expected to make weight estimates. On most vessels you can make an estimate on the tows you sample for species composition and estimate the weight of some non-sampled tows as well. If you are using your estimate for the OTC, that is a higher priority for your work than sampling the catch composition.

You must make or verify each component of the estimate. Do not make any total weight estimates simply "by eye." If you use preexisting height or length marks, or a vessel's weight scale, check them for accuracy. Record all dimensions and calculations in your logbook and your estimates on Form 2US whether you believe it to be a good estimate of total catch or not. There are many variables in estimation of total catch weights. Even if the catch is weighed later, it may already have been sorted or the scale may the tared for "water weight" or other factors. When your observer estimates are used as the OTC, record them in both fields on the Form 2US.

### Methods for Observer Estimates of Codends

**Options for Catcher Boats:** Make volume estimates (a) of checker bins, (b) of codends or (c) of codend sections added together. Convert the catch volume to a weight estimate using the observer's density sampling data or NMFS specified density.

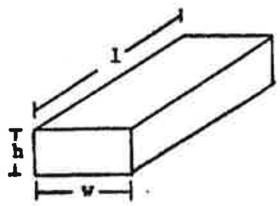
**Options for Catcher/Processors:** Make volume estimates (a) of live tanks or holding bins or (b) of codends. Convert the volume to a weight estimate by using your density sampling data unless given a specific density value to use.

On trawlers, a volume estimate from a fish bin is preferred over a codend volume because a solid sided container is usually an easier, more regular shape to measure than the expandable tube of a codend. However, codend volumes are more commonly used for observer estimates because live tanks may not be accessible for measurements, may have seawater in them, or they may not hold the entire catch at one time.

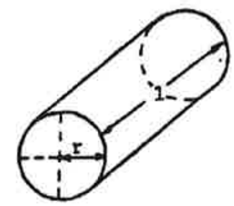
$$\text{Catch weight (mt)} = \text{Volume } (m^3) \times \text{Density } (mt/m^3)$$

### Methods For Calculating Volume: Codend Volume

Whether the whole codend is pulled onto the trawl deck before zippers are pulled, or only a few sections at a time are on deck, the first step in the estimation of the volume of fish in the codend is to decide which geometric shape your "solid" most closely resembles: a rectangular solid, a cylinder, an ellipsoidal solid, a semi-ellipsoidal solid, or perhaps a combination of two of these shapes. When the net is very full, the most appropriate formula to use may be the one for a cylinder. Catches which don't fill the codend to capacity may be flat on top but may fill the trawl "alley" width. A rectangular solid formula would work well in that case. Nets of 2 to 12 mt may look more like a pear. Use your judgement to estimate what the dimensions would be if you could "square it up."

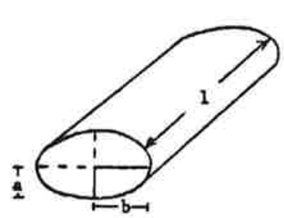



Rectangular solid
Volume = height x width x length
V = hwl

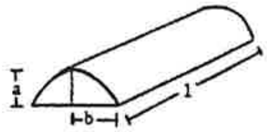



Cylinder
Volume = $\pi$ x radius$^2$ x length
V = $\pi r^2 l$

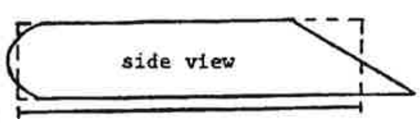
($\pi$=3.1416)

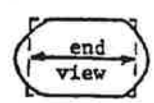



Ellipsoidal solid
Volume = $\pi$ x short radius x long radius x length
V = $\pi abl$




Semi-ellipsoidal solid
Volume = $\frac{1}{2}\pi abl$
V = $\frac{1}{2}\pi abl$




(Allowances can be made for irregular shapes or partially filled portions of the net by the way in which the measurements are taken.)

You will need to determine length, width and height of the codend to use with the most appropriate formula for volume. Look for measurement marks which may have been made by previous observers along the trawl alley length; measure the alley width. Look for height marks on posts or a gantry. Remember when sighting across a net to a reference mark for height, your eye level should be level with the top of the net (as much as possible). You can also gauge net height based on your height with boots on (e.g., at your shoulder or nose). Be careful, never stand next to a net if you could get pinned by it against the side of the trawl alley -- nets slide and roll! When only part of a net is landed at a time, the best place to gauge the height of the net may be the top of the ramp where the net breaks over onto the deck. Where the net is greater or less than a pre-measured distance, actual measurements of the difference are preferable over dimensions estimated by eye but will take a couple more minutes to do. Take actual measurements if possible and, failing that, estimate the dimensions by eye and record and label this information as such in your observer log. If a dimensional measurement varies, take a measurement at several points and average them.

Remember that by regulation, part of the vessel's responsibility is to notify you 15 minutes before fish are brought on board, allow you free and unobstructed access to the trawl or working decks and to provide reasonable assistance in measuring decks and codends (refer to page ?). Do your part by planning the most efficient method for taking your measurements. The deck crew wants to empty the net as quickly as possible. Talk to the skipper and the deck boss after you have looked the situation over. They may have some good suggestions from working with previous observers that you should consider. If you need assistance, having one of the deck crew help you regularly will help everyone.

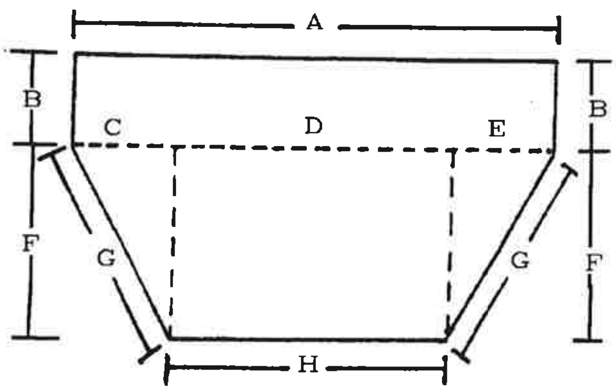
On vessels less than 125 feet in length, it is common that a full codend will be longer than the trawl deck and can only be emptied several sections at a time while the remainder hangs off the stern ramp, still in the water. Codends have reinforcing cables or "expansion straps" around their circumference and "riblines" (which may be rope lines or are often made of chain) running their length. These straps and riblines will usually limit extreme bulges and the volume of fish between some straps will be similar. Similar sections of the net can be added as a consistent unit of volume. This can be added to the volume of odd sized sections of the codend (usually at each end) for a total net volume. *Do not measure volume of net sections on only one catch and thereafter simply count the number of full bands.* Like any mesh bag, when the net is very full, the mesh will expand and bulge and there will be more tonnage per section.

In your logbook, record the dimensions of the net for each catch and calculate the volume in cubic meters using the appropriate formula Then multiply the volume times the density, obtained as explained below, to obtain the metric tonnage of the catches.

### Methods For Calculating Volume: Bin Volume

On some ships, it may be possible to estimate the catch size by the volume of fish in a live tank, holding tank (e.g., surimi vessels) or checker bin (e.g., catcher boats). While this method is preferred over codend volume it may not be possible for a number of reasons. You may not be able to see into the bin well enough to determine the depth of fish; there may be too much water in the tank; the tank may be too difficult a shape to measure; or there may be *too little depth* of fish for the area of the bin they're in.

Measure the fish bin into which the fish will be emptied to obtain the area in meters squared. If the fish bin is shaped like a rectangle or square, it would be relatively easy to calculate the volume. Simply multiply the floor area (length x width) by the height of fish. However, many fish bins are irregularly shaped, in which case the floor area of the bin must be broken into sections which can be easily measured. The example below shows how one fish bin was broken into shapes easily calculated or measured to obtain floor area.




**Useful Formulas You May Need**

Area of a circle = $\pi r^2$  Circumference = $2\pi r$  ($\pi = 3.1416$)
Area of a square or rectangle = length x width (In diagram above: A x B)
Area of a triangle = ½ base x height (In diagram above: ½ E x F)
Length of triangle's hypotenuse in diagram above: $C^2 + F^2 = G^2$ *and*, $\sqrt{G^2} = G$
**Note:** Surface area multiplied by height = volume
For bin floors with a conical shaped depression: Volume of a right angle cone = $1/3\pi r^2 h$

The height of fish in the bin is the third dimension needed to determine volume. If the bin is sided with common width boards of known dimension, use the height of each board to estimate the height of fish in the bin. If the bin is sided with metal plate, ask if you can use some paint to make a height gauge at four places on the sides. If the floor of a bin is a half cylinder and/or is sloped, it may be easiest to determine the volume to level and then mark the sides of the bin from level to the top in increments of 10 cm. The volume to level would be added as a constant to the level area times the average depth from level to the top. Alternatively, the tank sides could be marked from the top down so you can calculate the volume of air above the fish (also termed ullage) and subtract that from the "full bin" volume. Be aware of overhead structures which may reduce the volume capacity of a bin when it is filled above a certain point.

To determine an average height of fish, it is best to measure the height of fish at four or more points around the inside of a bin. Height gauges painted on the sides of tanks below deck might be read by standing on the trawl deck and looking down into the tank through the hatch(es) or you may be able to go below to the tank and see in over the sides or through a viewing port. With deck bins, some observers have improvised a calibrated "dip stick" to measure fish depth at several points. Again, the area of the fish bin (a constant) multiplied by the height of fish from that catch equals the volume. Volume times density equals the catch weight.

## Methods For Calculating Density

Codend or bin volume (in $m^3$) is multiplied by a weight per cubic meter ratio (termed "density") to obtain a catch weight estimate for a specific haul. When sampling catches of ≥ 95% pollock, use our calculated density of 0.93 $mt/m^3$. If you are sampling catches of any other species mix, you must calculate fish density for that tow.

Density is variable both within a haul and from tow to tow. From each sampled haul, random samples must be taken to compute density for that haul. Calculate average density values for the day or area to use for observer catch weight estimates of unsampled hauls.

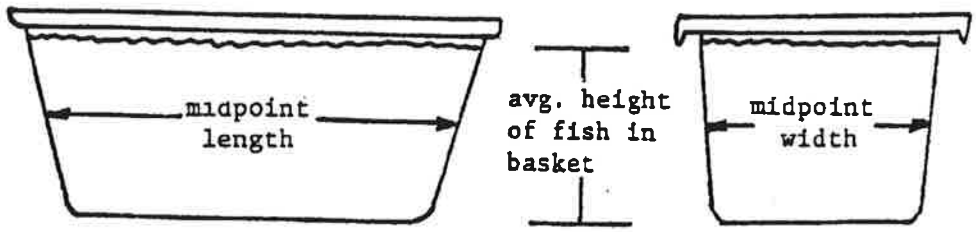
Measure the volume of the density samples in any simply shaped container that holds five hundred kilograms or less (half a cubic meter). If the only small-volume container available is a blue observer basket, a minimum of four baskets should be used to calculate density.

First determine the volume of fish in the sample. When taking a four basket sample, fill all the baskets to the same level. (Unless you want to measure and record the depth of fish in each basket and calculate and sum the volumes.) One centimeter difference in the height of fish in the basket, for a given weight, can change the resultant density value by several percent. This in turn, changes the volume to weight conversion of a codend by several **tons!** The volume for three fill levels of the standard blue basket is provided:

| Top of Basket to Fish Level | | Length | Width | Height | Volume |
|---|---|---|---|---|---|
| 0 cm | Full to rim | .52 m | .365 m | .290 m | .055042 $m^3$ |
| 5.5 cm | To bottom of handle | .51 m | .360 m | .235 m | .043146 $m^3$ |
| 15 cm | To bottom of handle reinforcing plate | .50 m | .350 m | .140 m | .024500 $m^3$ |

If you are using a different fill level than the ones above or a different container, measure carefully. The basket sides are sloped slightly, so use the midpoint width and length measurements. Remember that the midpoint is half the distance from the bottom to the level **<u>of fish</u>** in the basket (or other container) not to the top of the basket.

Midpoint length x height of fish x midpoint width = total volume




Examine the way that fish are packed in your basket or small container. It is important that it approximates the way that fish are packed in the fish bin or codend. For instance, if you have very large fish in your basket, such as Pacific cod or turbot, they may not be lying flat on top of each other as they would in a large fish bin. The density of the fish in the basket will be less than the density of fish in the bin because there are more spaces or air pockets between the fish in the basket. It *is* appropriate to *arrange or settle* the fish into the container to minimize the interstitial spaces *but do not compact or smash* the fish in an attempt to duplicate the force in the codend. Your resulting density value would be too subjective. A better solution is to find a larger container or have one built.

After the total volume of the sample is calculated, sum its total weight. Divide the total sample weight by the total volume to obtain the density value for that haul. If you are not confident in your sample technique, examine your work. Remember it is important to take a *random* sample of the catch and to fill all your baskets consistently to the same level. Using the volume of the fish in the codend or live tank and the density of those fish, you can calculate a total catch weight estimate.

In summary, there is no need to be surreptitious about your estimates of catch weight or composition. In some cases, captains have improved their record keeping by learning from the observer. On the other hand, do not argue with the captain about catch estimations. His logbook hail (deck) weights do not have to equal or even approximate yours.

**Appendix 3: Instructions for density sampler operation during the 1997 A-season**

1. Fill the sampler to the 530-570 mm level on the rulers. Stir the fish by hand to settle them, then level them off. Place the lid on top of the fish and press down firmly to settle it.

2. For each tow, record a volume estimate for a) no weight on lid, b) 20 kg weight, and c) 50 kg weight. The same fish can be used for each measurement. Make sure the weight is placed in the center of the lid.

3. To obtain volume in $m^3$, take the average of the three ruler readings in mm to the top of the fish. Use a flashlight to read the ruler. The following formula to obtain the volume:

$$Volume = 0.03492 + 0.0002647(Average)$$

The white plastic lid is 18.5 mm thick and the measuring card is 1 mm thick, so if you measure to the top of the measuring card you should subtract 19.5 mm from your measurements, then take the average.

4. Use the same fish to obtain four basket densities. Four baskets filled to the base of the handle should fill the density sampler to the requested level. Do not attempt to adjust your basket sampling technique to obtain densities that you think are more appropriate.