A Mechanical Device to Sort Market Squid, *Loligo opalescens*

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Introduction

Squid is an excellent source of protein and lacks the small bones which some consumers find objectionable in certain finfishes. Indeed, high quality squid is regarded as a gourmet food in many countries, particularly in the Orient and Mediterranean Europe. However, U.S. consumers are hesitant to buy whole squid because of its appearance and the need to clean it. Use of automatic skinning and eviscerating machines (Singh and Brown, 1980) is expected to improve the acceptance of squid by U.S. consumers, although several other problems related to processing and handling must be solved before the market for squid rings or fillets can be fully developed.

The fishery for market squid, *Loligo opalescens*, has considerable room for expansion[1]. However, the small size of this species, coupled with high manual processing costs and high ex-vessel prices in poor harvest seasons, can have a severe impact on the industry.

Automated sorting by size can make machine-packing of market squid more economical. It is also desirable when automatic cleaning machines are used because damaged squids or finfishes can be easily removed before entering the cleaning machines. In addition, better yields are possible if the cleaning machines are fed with uniform-sized squids.

Additional advantages accrue if males can be separated from females. Female squid can be sold whole, with roe (at higher prices), to Japanese markets where the roe is part of several traditional dishes. This study was made to determine the physical properties that affect squid sorting, and to develop techniques for mechanical sorting of *L. opalescens* by sex and size.

Squid Characteristics

Squids are mollusks of the class Cephalopoda, and have eight sessile arms and two tentacular arms strongly attached to the head (Fig. 1). The mantle looks like a cone that surrounds and is attached to the visceral mass in a line at the back. The "pen" or "backbone"

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[1]Guide to underutilized species of California. 1983. Underutilized Fishery Resources Task, Tiburon Laboratory, Southwest Fisheries Center, NMFS, NOAA, 3150 Paradise Drive, Tiburon, CA 94920. SWFC Admin. Rep. T-83-01, second ed., 26 p.

ABSTRACT—Automatic sorting of market squid, Loligo opalescens, *is expected to facilitate machine-packing, thereby producing better yields and higher earnings. We found the tentacle-and-head:mantle length ratio suitable for sorting these squid by sex. That ratio was >0.80 for all males and <0.65 for all females, with a 99.5 percent confidence level. A laboratory-scale machine was built to sort squid by sex and size based on those ratios. The ratios increased for squid stored more than 1 day in ice.*

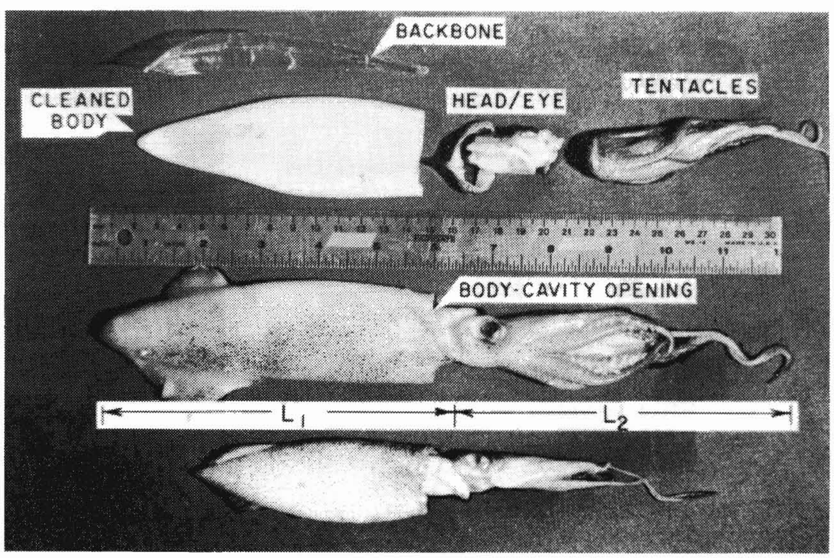


Figure 1.—Cleaned squid parts, above, and whole squid, below (from Singh and Brown, 1980).

is also situated in this line. Eggs and sperm sacs are located at the tip of the cone.

A full description of squid anatomy was published by Berry (1912). Although Berry stated "arms stout and rather short in the male, sometimes a little longer in the female," Fields (1965) showed that *L. opalescens* arms are proportionally longer in males ($\bar{x}$=165 mm) than in females ($\bar{x}$=150 mm).

Those sizes are small compared with such North Atlantic species as *L. pealei* and *Illex illecebrosus* (Berk, 1974), or the squids yari ika, *L. bleekeri*; kensaki ika, *L. edulis*; surume ika, *Todarodes pacificus*, and others caught by Japanese fishermen.

Market squid harvests in California average about 15,000 metric tons (t) per year (discounting El Niño years), but this might be increased to about 100,000 t annually (Voss, 1973) if demand increases.

Whole frozen market squid is inexpensive at retail compared with finfish or other seafoods ($3.57/3-pound box[2]), but its appearance and the need to clean it are the main reasons for its lack of popularity. Squid cleaned by hand would be very costly owing to high labor costs, and mechanization can significantly reduce squid processing costs.

Advantages of Sorting

Most female *L. opalescens* contain roe during the California fishery. Thus, their yield is low when cleaned as the roe may be lost. However, if the sexes are separated, the males can be cleaned by machine, providing a superior yield, and it is expected that the females can be sold whole, with roe, to foreign markets, especially Japan, at a better price.

Machine yields can be further improved by processing squids of uniform size and adjusting the knife position to provide maximum yield. Improper adjustment or processing squids of varying sizes can leave portions of the head attached to the tentacles or result in mantle cuts that are so small that the pen will not be detached in later operations.

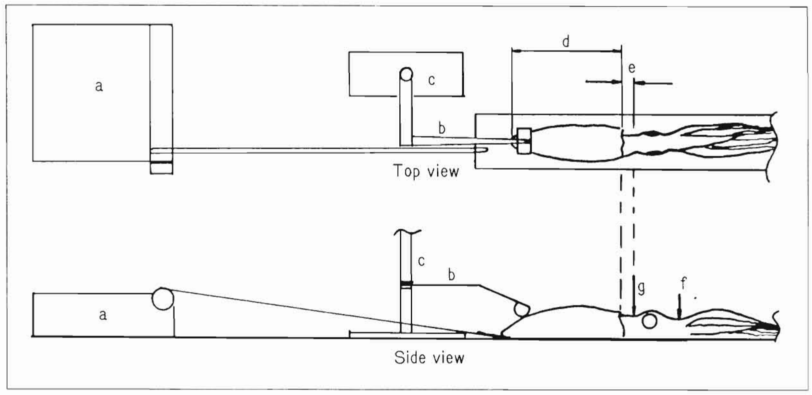


Figure 2.—Laboratory arrangement used to record squid profiles; a = chart recorder, b = cantilever beam, c = support, d = mantle length, e = elongation, and f and g = relative minimums.

Processing squid of uniform size can also facilitate packing of whole squid and result in a more uniform product with savings in both labor and equipment. Instead of packing by weight, packing could be done by the number of squid and of a given size. Packing can be easily automated to different degrees, or remain manual, but even packing by hand would be made faster.

Materials and Methods

Four lots of squid (A, B, C, and D) were used in this study. Lot A, whole, frozen *L. opalescens*, was purchased from two local supermarkets in 1983. Packages had a nominal weight of 0.454 kg (1 pound) and storage time was unknown. For all the tests with frozen squid, the boxes were allowed to warm up during 2 hours at room temperature, and were then opened and immersed in tap water. A small amount of fresh water was circulated until thawing was complete.

For Lot B, fresh squid samples in ice were collected at Monterey Bay, Calif., from the first boat to dock in June 1983. These samples were separated at the weighing station and layered with ice in an ice chest. Sufficient ice was used to cool the squid and maintain it at 0°C during the 3-hour transportation to the University of California laboratory in Davis. Ratios of tentacle-and-head to mantle length (hereafter called the tentacle:mantle length ratio) were determined the next morning. The total lengths (including tentacle, head, and mantle) measured for squid samples of Lot B ranged from 102 to 108 mm for males and from 110 to 112 mm for females (99.5 percent confidence level).

During 1984, the effects of El Niño made California market squid scarce. As a result for Lot C, fresh squid on ice was air-shipped from Oregon, but their size was also small, i.e., similar to California squid. The mantle length of 99 percent of the males was 86-91 mm. For 99 percent of the females, the mantle length range was 93-99 mm. For comparison purposes, Lot D consisted of frozen *Illex illecebrosus* shipped by air from the U.S. east coast.

Experimental Procedures

Profile Measurements

The laboratory arrangement for profile measurements is shown in Figure 2. Squid samples from Lot B were used in these experiments. The squid samples were placed by hand, backs up, on a polyethylene film. Each sample was caused to slide, mantle-end first, over the surface of the polyethylene film to simulate the position that squids take while sliding down. Small quantities of tap water were periodically splashed on the film to keep the surface wet so the squids could slide, but care was taken to keep the underside dry. The whole arrangement was located on a laboratory

[2]Three-pound box of market squid purchased by the authors at a large Davis, Calif., supermarket, Nov. 1984.

bench. The polyethylene film was attached by cellophane tape to the chart of the recorder. A strain-gauge apparatus (Fig. 3) was used to record the the squid profile described by cantilever beam. With this arrangement squid profiles can be recorded regardless of chart speed. However to evaluate statistically the different body proportions of each sex, mantle length and tentacle-and-head length were manually measured.

The typical profiles of *L. opalescens* are shown in Figure 4 where differences between male and female tentacle lengths, and both the thickness and length of the female squid are easily observed. These profiles were obtained with the chart recorder and the cantilever beam arrangement (Fig. 2) using fresh squid that was held on ice for 3 days from Lot B.

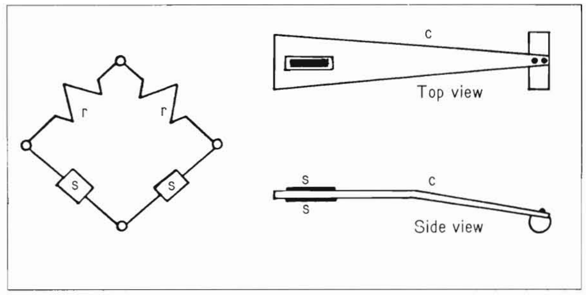


Figure 3.—Sensor used to record squid profiles, and bridge connections; c = cantilever beam, s = strain gauges, and r = resistances.

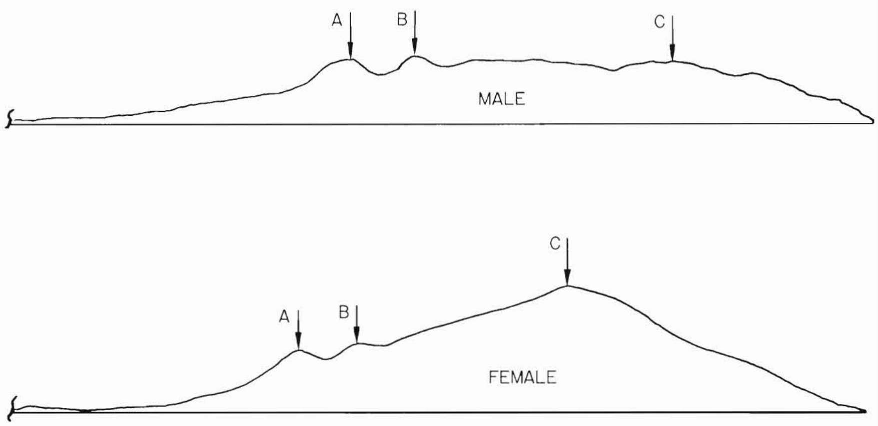


Figure 4.—Typical profiles of male and female *L. opalescens*, where A, B, and C = characteristic maximums for eyes, tentacle insertion, and mantle, respectively.

Tentacle:Mantle Length Ratios

Length measurements were made on a sample of 153 fresh squids taken in bulk from about 250 squids of Lot B. Tentacle-and-head length, and mantle length were also determined for each squid. The tentacle:mantle length ratio was then computed for the 153 squids. The measured samples were also examined individually whether they were male or female by dissecting each sample. The tentacle:mantle length ratio means computed were significantly different between males and females (0.8245 for males and 0.6418 for females). With a confidence level of 99.5 percent, the ratio is >0.8035 for all males and <0.6529 for all females.

The following day the tentacle:mantle length ratio was redetermined on a sample of 161 squid from Lot B. The means of this ratio was found to be higher for both males and females indicating that the squid undergo physical changes during storage.

From the first sample of 74 squid taken from Lot C, the tentacle:mantle length ratio was >0.8291 for 99.5 percent of the males and <0.7171 for the females. This upper limit for the ratio of the females is high because only 22 females were in the sample.

The tentacle:length ratio was also computed from manual measurements done on Lot D of the U.S. east coast samples of *Illex illecebrosus*. These squids had proportionally longer mantles and were much bigger than the *L. opalescens*. The mantles of the examined specimens were very thick, although all of them appeared to be in a postspawned condition. In proportion to the tentacles, the sizable arms were much longer and thicker. The tentacle: mantle length ratio was >0.7526 for the females, with a 99.5 percent confidence level, and <0.7457 for the males with the same confidence level. Although the possibility of males with greater tentacle:mantle length ratios or females with smaller ratios is small, the interval between the two ratios is less than 1 percent of the value of either ratio. This small difference means a very high resolution is necessary in any digital data acquisition system to be used. Also, with *I. illecebrosus*, the higher tentacle: mantle length ratio corresponds to the females, while on *L. opalescens* the higher ratio corresponds to the males. This preliminary analysis indicates that the approach to sorting presented here can be successfully used for *L. opalescens* but is unsuitable for *I. illecebrosus*.

Prototype Development

The significant difference between the tentacle:mantle length ratios suggested that an electro-mechanical system that

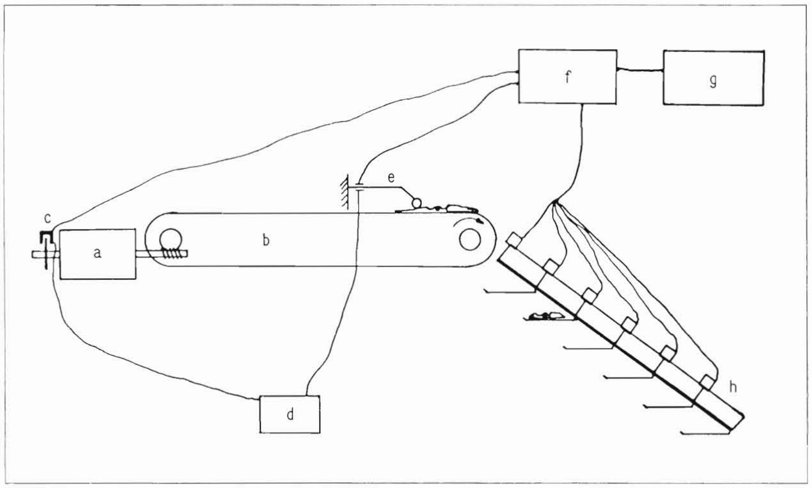


Figure 5.—Prototype machine; a = motor, b = conveyor belt, c = photoelectric unit with light emitting and detector diodes, d = 5V power supply, e = sensor, f = data acquisition and control unit, g = computer, and h = selector unit.

senses this length ratio could be useful in automatic sorting of market squid by sex.

The prototype developed in this study (Fig. 5) consisted of a cantilever beam mounted rigidly over a conveyor belt. Several materials were tested for the conveyor belt. All the flat belts tested failed to retain the squid under the roller when water was present. A perforated plastic belt was adopted so the water could drain through the holes. This belt (1.25 mm thick with round 2 mm diameter perforations 2 mm apart) gave satisfactory results. Cleaning was accomplished easily using water, brush, and soap.

Two strain gauges and two high quality resistors attached to the base of the cantilever beam were arranged as a Wheatstone bridge circuit (Fig. 5). Electricity was provided with a regulated 5V DC power supply. Output voltage was measured with an HP 3490A digital voltmeter (Hewlett Packard[3], Palo Alto, Calif.). The same power supply was used to provide an external trigger for the voltmeter with the signal required to take readings. A disc with two perforations was mounted on the shaft of the variable speed electric motor that drives the conveyor belt. A unit consisting of a light emitting diode and a detector diode was mounted so that the light was entirely blocked, except when the perforation matched with the emitter-to-detector line (Fig. 5). Thus, the readings from the voltmeter were synchronized with the displacement of the belt and were independent of the belt speed.

The digital output from the voltmeter was sent to a desk-top HP 9825T (Hewlett Packard) computer. As squid were detected, measured, and profiled, the values were entered, analyzed, and stored, starting with the tentacles. Charting profiles beginning with the tentacles was preferred because spurious relative minimums are more likely to appear within the mantle section (Booman, 1985). Maximum sampling speed of the HP 3490A voltmeter is three readings per second, and since nearly 100 readings are desirable to evaluate accurately the length of a large squid, 30 seconds were necessary for this particular step. A flowchart of the computer program is shown in Figure 6A and 6B.

Using this system, it was possible to sort squids by sex and size. The first tests were run using previously frozen squid (Lot A), since fresh squid was not available at the time. The samples were identified as males or females, and were sized, using arbitrary standards, as long, medium, and small, i.e., longest one-third, smallest one-third, etc.

The program for this voltmeter worked as follows: The light emitting and detecting head placed over the belt motor shaft signaled the HP 3490A multimeter to take readings at equal displacements of the belt. The computer read the multimeter when it was ready and compared the last reading with the constant in the memory that corresponded to the bottom-line deflection of the cantilever beam. When the value read was greater than the constant, it was stored in computer memory as the first reading. Consecutive values were stored until the detected deflection of the beam was no longer greater than the constant. When information storage ended, the computer started analyzing the data from the tentacle end. If the two minimums that corresponded to the tentacle-head section and the head-mantle section were not found, the program did not recognize the perturbation as a squid, printed a message, and started reading again. If the two minimums were found, the actual number of readings from the last recorded value until the second minimum were used to compute the tentacle length. The mantle length was compared with arbitrary standards, and the sample number, its size, sex, and the tentacle: mantle length ratio were printed out.

To increase the conveyor belt speed, we had to consider another voltmeter. The HP 3421A was selected because it is ten times faster than the HP 3490A when it is set to read voltages in the 0.1-10 V range. However, to use the HP 3421A, several modifications were necessary and are discussed by Booman (1985). A selector (Fig. 5) was constructed as a separate unit. This selector was driven by the HP 3050B data acquisition system.

To make the system fail-proof, certain ranges for the mantle and tentacles need to be incorporated. The same criterion was used to detect the squid that had been under excessive pressure during handling, and the females with little roe content.

[3]Mention of trade names or commercial products or firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

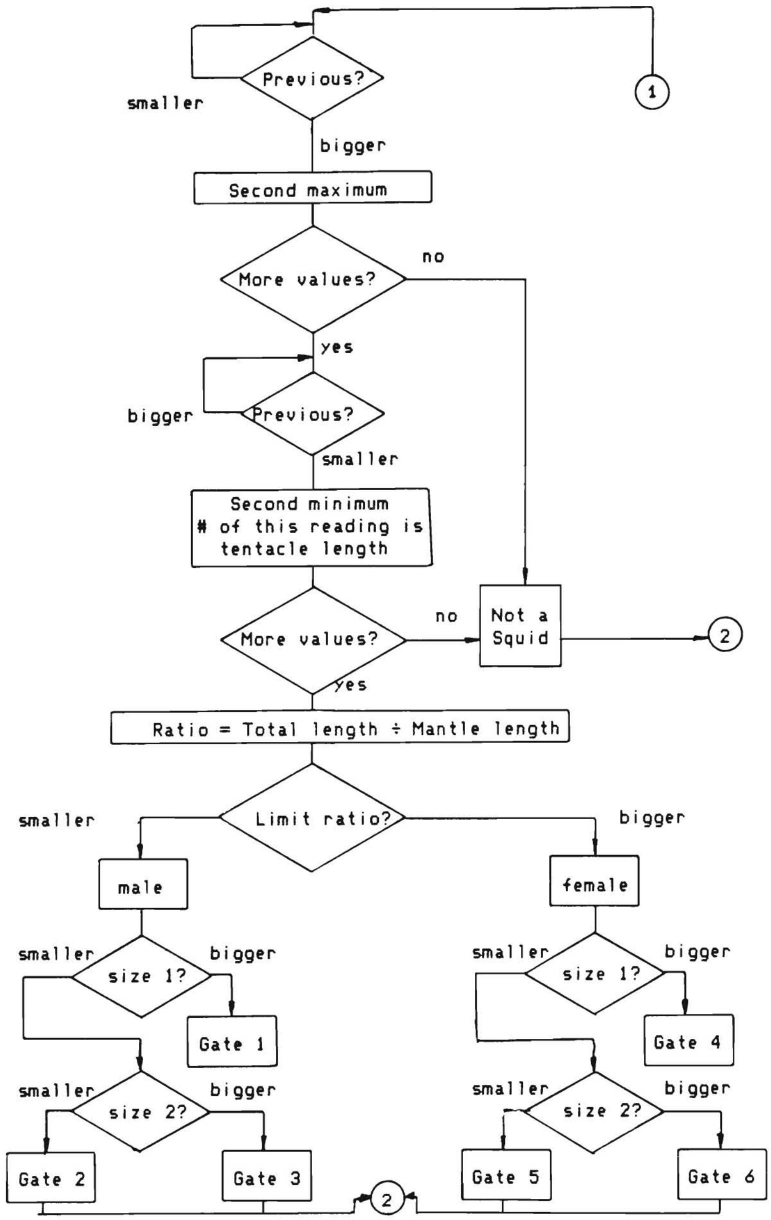


Figure 6A.—Flowchart of the computer program.

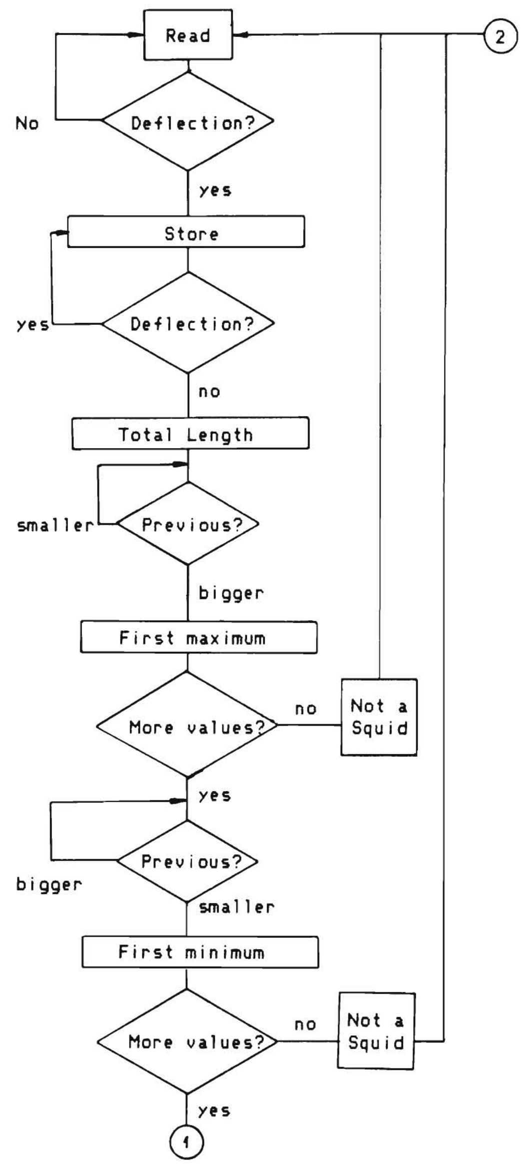


Figure 6B.—Flowchart of the computer program.

Tentacle:mantle length ratios and confidence intervals are shown in Figure 7 as a function of time from capture. The ratio measured by hand increased with time and the ratio measured by the prototype machine decreased. The reason for the opposite behavior of the means is that the mantle length is computed as the total length minus the length of the tentacles and head. The end of the head coincides with the location where the mantle portion starts in fresh squid. With time, the attachments of the internal organs to the mantle begin to relax, and a portion of the squid that was initially inside the mantle becomes visible as a long neck. Since the prototype machine uses the criterion of a relative minimum to find the point where the head ends, and this point is just at the end of the head, the neck that came off the mantle is considered part of the mantle by the prototype. A special procedure was developed to compare data obtained with the prototype machine with data obtained manually (Booman, 1985).

The tentacle length seen by the prototype also depends upon calibration. It was necessary to define a minimum

Figure 7.—Tentacle:mantle length ratios of *L. opalescens* during iced storage. Asterisks indicate lengths measured with the prototype machine; lines around data points indicate 99 percent confidence intervals.

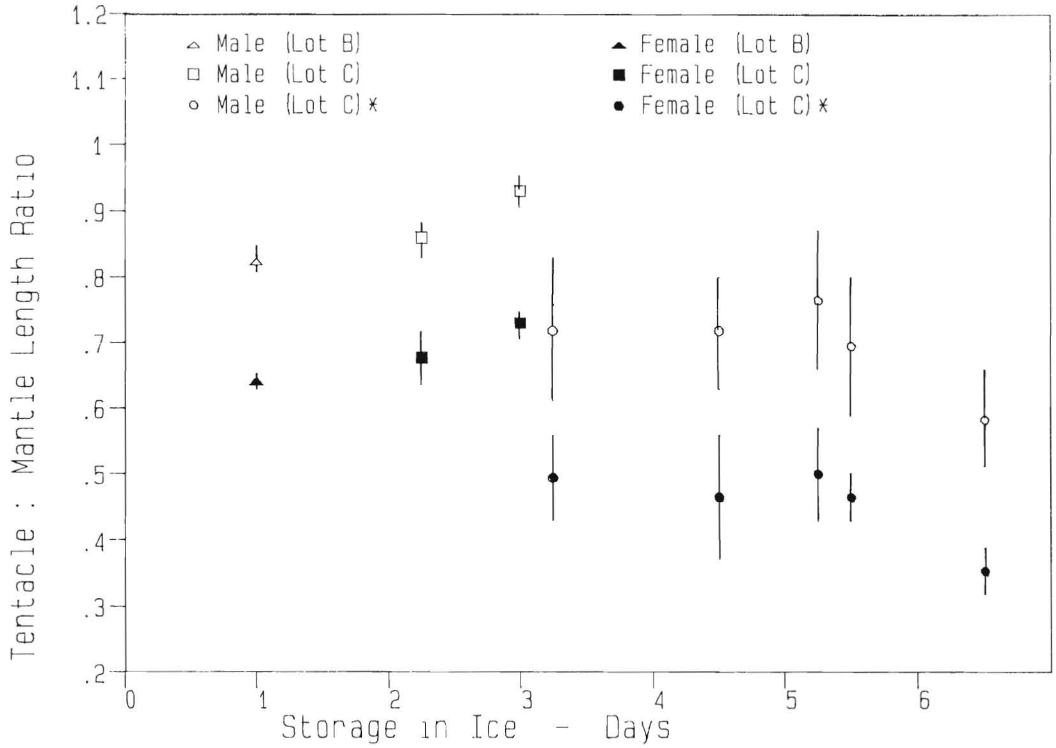
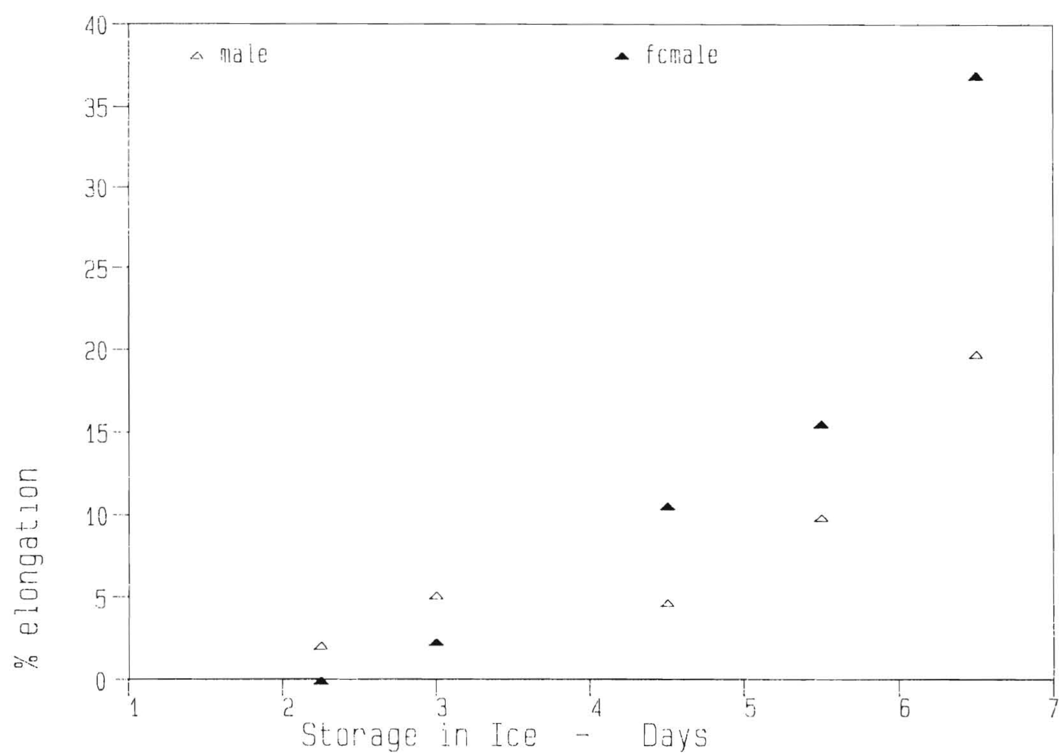


Figure 8.—Elongation of *L. opalescens* during iced storage.



thickness to be used by the machine as the presence of the tentacles, and this thickness must be set greater than the thickness of the tips of the two arms plus the amplitude of belt vibrations. It was also necessary to define a minimum noise level for the detection of the relative maximums and minimums. The elongation or increase in the total length of the market squid, which is most likely due to the physical changes that occur during storage, is shown in Figure 8 as a function of time from capture.

Conclusions

We found that market squid can be size-sorted using a mechanical device that contains a mechanical sensor, a microprocessor, and solenoid-driven gates. Such a full-scale operation will facilitate the processing and packing of market squid.

The tentacle:mantle length ratio for *L. opalescens* was determined to be 0.82 for males and 0.64 for females. With a confidence level of 99.5 percent, the ratio is >0.80 for all males, and <0.65 for all females. The tentacle:mantle length ratio remains constant for both sexes during the first day from capture. We also found that the elongation of *L. opalescens* during storage could be used for the constant monitoring of that aspect of squid quality in processing plants.

Acknowledgments

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