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## THE RELATION OF LIVER TO BODY WEIGHT IN THE SWORDFISH (*XIPHIAS GLADIUS*)[1]

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## INTRODUCTION

Louisburg, Nova Scotia, is the center of a thriving swordfishery from which the dressed carcasses are sent in ever-increasing numbers by rail and boat to markets in Canada and, via Boston, throughout the United States. In August of 1938 the Second Lerner Cape Breton Expedition made Louisburg its headquarters for the continuation of its swordfish researches which were begun in 1936. For a large part of our stay there the weather was foggy and the sea choppy. These conditions rendered swordfishing difficult and as a result the number of fresh specimens dwindled to nothing.

During this enforced lay-off from our anatomical studies, the Messrs. Lewis, of Lewis and Company, kindly allowed me to copy their swordfish purchase records for 1935, 1936, 1937 and a part of 1938. These records consist of a day-by-day tabulation of their purchases from individual fishermen of body carcasses and the corresponding livers. In most cases the records are of multiple purchases, e.g., 2350 pounds of carcasses and 31 pounds of livers. Many single items were recorded, however, to make a total of 909 fishes with their corresponding liver weights.

Inasmuch as the body weights which figure in the following discussion are not "whole" but "dressed" weights, an explanation of the method of dressing is desirable. The object of the fisherman in cleaning his fish is, of course, to preserve as much of the edible portion as possible. This results in a most economical method of dressing, which is quite standardized at this port. In order the following steps are taken:

1. The dorsal, anal and pectoral fins are removed by a saw;
2. The caudal fin is removed just posterior to the shallowest dimension of the peduncle;
3. The head is removed, but the pectoral girdle is retained;
4. A slit is then made the length of the abdomen;
5. After carefully excising the liver the viscera are removed through the neck of the carcass;
6. The carcass is then carefully washed and scrubbed;
7. The weighing of body and liver follows immediately.

The commercial aspect of the fishery insures an unusual consistency in this dressing process, for each fisherman leaves as much paying weight on his carcass as the buyer will allow.

Through the good services of the Messrs. Lewis we interrupted the usual procedure of the fishermen long enough to weigh eight swordfishes BEFORE and AFTER dressing to serve as a check upon the weight lost with the removal of the fins, viscera, etc. The distribution table below shows the percentage loss of weight in these eight cases. It is seen that 24 or 25 per cent is usually lost in this process.

[1] Results of the Michael Lerner Ichthyological Expeditions. No. 24.

| Percentage of weight lost in "dressing" | | | | | | | |
|---|---|---|---|---|---|---|---|
| 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
| Number of swordfishes | | | | | | | |
| 1 | 0 | 2 | 3 | 0 | 1 | 0 | 1 |

The possession of these extensive day-by-day records of liver and body weight[1] suggested an investigation to see if weekly fluctuations of liver weight were observable and, if so, whether they followed a definite pattern in the three years and a half covered by the data. For instance, it would be interesting to know whether or not the liver weight rose to a peak at the middle of the Cape Breton season and then fell off in the end of September. If such were the case the inference might be made that the abundance of food which brought the fish north to Cape Breton (Nichols and LaMonte, 1937, p. 1) resulted in the storage of surplus energy in the liver in the form of glycogen and/or fats. This period of plenty might reach a peak during August and then, with the departure of the food-fishes, these stored foods would be drawn upon until the swordfish caught up once more with his accustomed prey in the form of herrings and mackerels.

The weekly fluctuations in absolute size of the body and liver are also records of interest, both to the fishermen and to the ichthyologist.

Last but not the least of the interesting facts to be deduced from the data is the rate at which the liver grows with reference to the body.

## THE DATA ARRANGED IN SIZE CLASSES

In Table I the grand totals and averages of each size class are recorded. As might be expected, it is seen that as the body weight increases the liver becomes relatively smaller. In the smallest group, 51–100 pounds dressed weight, the liver is 3.2 per cent of the body whereas in the 551–600 pound group the liver is 1.7 per cent of the body.

TABLE I

| Body Weight Classes | Number of Fish | Average Body Weight (Dressed) | Average Liver Weight | Av. Liver × 100 / Av. Body |
|---|---|---|---|---|
| 51–100 | 10 | 89.4 | 2.9 | 3.24 |
| 101–150 | 73 | 132.9 | 3.3 | 2.48 |
| 151–200 | 198 | 176.4 | 4.3 | 2.47 |
| 201–250 | 225 | 222.5 | 5.2 | 2.33 |
| 251–300 | 169 | 273.0 | 6.3 | 2.32 |
| 301–350 | 115 | 323.4 | 7.4 | 2.28 |
| 351–400 | 68 | 373.1 | 7.8 | 2.08 |
| 401–450 | 26 | 421.7 | 8.3 | 1.97 |
| 451–500 | 16 | 474.6 | 8.6 | 1.83 |
| 501–550 | 6 | 516.1 | 9.3 | 1.80 |
| 551–600 | 3 | 566.0 | 10.0 | 1.76 |

As calculated from the group averages in Table I, the "k" or constant differential growth rate of the liver is 0.724. In other words, as the body weight increases one unit, the weight of the liver increases by slightly more than seven-tenths of a unit. Obviously, therefore, the liver becomes relatively smaller as the general body weight increases.

Calculating the regression of liver weight on body weight gives us theoretical liver weights corresponding to the observed values of body weight (using the method of Simpson and Roe, 1939, pp. 365–366). Table II contrasts the theoretical weights with those observed. In only two cases is the deviation greater than plus or minus 0.3.

TABLE II

| Size Classes | Actual Liver Weight | Theoretical Liver Weight | Deviation |
|---|---|---|---|
| 51–100 | 2.9 | 2.7 | 0.2 |
| 101–150 | 3.3 | 3.5 | 0.2 |
| 151–200 | 4.3 | 4.4 | 0.1 |
| 201–250 | 5.2 | 5.2 | 0.0 |
| 251–300 | 6.3 | 6.0 | 0.3 |
| 301–350 | 7.4 | 6.8 | 0.6 |
| 351–400 | 7.8 | 7.5 | 0.3 |
| 401–450 | 8.3 | 8.3 | 0.0 |
| 451–500 | 8.6 | 9.0 | 0.4 |
| 501–550 | 9.3 | 9.5 | 0.2 |
| 551–600 | 10.0 | 10.2 | 0.2 |

For the individual years 1935, 1936, 1937, 1938 the "k" value is 0.709, 0.740, 0.858, 0.731, respectively. The reason for the sharp upward trend in 1937 is obscure, unless it may be correlated with a markedly bountiful food-year for the swordfishes in

[1] The data upon which these observations are made are on deposit in the files of the Department of Comparative Anatomy, American Museum of Natural History, New York, N. Y.

which a great deal of fat was stored in the livers.

The average body and liver weights for the combined data are, respectively, 251 pounds and 5.7 pounds. Table III indicates how nearly this norm is approached each year. The increased growth rate ("k," 0.858) of the liver in 1937 is reflected in the averages for that year when the body falls to 240 pounds while the liver remains at 5.7 pounds.

TABLE III

| Year | Average Body Weight | Average Liver Weight | Liver × 100 / Body |
|---|---|---|---|
| 1935 | 255.35 | 5.7 | 2.2 |
| 1936 | 252.13 | 5.8 | 2.3 |
| 1937 | 240.21 | 5.7 | 2.3 |
| 1938 | 250.07 | 5.1 | 2.0 |
| 1935–1938 (incl.) | 251.0 | 5.7 | 2.2 |

Raven and LaMonte (1936, pp. 11, 12) in a discussion of the anatomy of the swordfish liver state that "two hundred and sixty swordfish, weighing 73,083 pounds (dressed), had livers weighing 1461 pounds, which is very close to 2 per cent of the dressed weight of the fish.... The smaller the swordfish, the greater its proportional liver weight; thus the fish dissected, which was one of the smallest obtained, had a total weight of 225 pounds and a liver of 6 1/2 pounds, or 2.8 per cent of its total weight."

It will be seen that Raven and LaMonte's average of 260 swordfish livers as 2 per cent of the dressed weight (actually 1.9 per cent) is extremely close to the average 2.2 per cent obtained on the basis of 909 specimens. Their dissected specimen had an extremely large liver for its size class. By deducting 25 per cent of the total weight an approximation of the dressed weight is obtained (169). For the size class 151–200 the average liver weighs 4.3 pounds and its relative size is 2.4 per cent. The theoretical liver weight for a 169-pound (dressed) fish would be 4.2 pounds. Their fish had undoubtedly been in Cape Breton's bountiful waters long enough to store excess food in its liver.

## THE DATA ARRANGED IN TEN-DAY INTERVALS

By arranging the data in ten-day intervals from July 15 through October 1, inclusive, and averaging the body weights and liver weights within these categories it was hoped that we might observe the seasonal fluctuations (Table IV).

periods following, the liver drops to 2.3 per cent but no lower. The next year, 1936, records a similar picture, except that the peak interval for the liver falls between September 3 and September 12 when 2.8 per cent is reached. In 1937, the year in

TABLE IV

| Ten-Day Intervals | Dressed Body Weight | | | | Average Liver Weight | | | | Liver × 100 / Body | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1935 | 1936 | 1937 | 1938 | 1935 | 1936 | 1937 | 1938 | 1935 | 1936 | 1937 | 1938 |
| July 15–July 24 | 274.6 | 275.0 | 236.8 | 272.0 | 4.6 | 5.1 | 5.7 | 5.7 | 1.6 | 1.8 | 2.4 | 2.0 |
| July 25–Aug. 3 | 192.0 | 269.1 | 233.4 | 248.3 | 4.4 | 5.9 | 5.9 | 5.2 | 2.2 | 2.1 | 2.5 | 2.0 |
| Aug. 4–Aug. 13 | 281.0 | 242.6 | 206.4 | 246.4 | 6.2 | 5.7 | 4.7 | 4.8 | 2.2 | 2.3 | 2.2 | 1.9 |
| Aug. 14–Aug. 23 | 262.7 | 231.2 | 252.2 | ..... | 6.2 | 6.0 | 5.6 | ... | 2.3 | 2.5 | 2.2 | ... |
| Aug. 24–Sept. 2 | 212.4 | 212.5 | 239.0 | ..... | 5.3 | 5.4 | 5.7 | ... | 2.4 | 2.5 | 2.3 | ... |
| Sept. 3–Sept. 12 | 234.9 | 238.6 | 230.0 | ..... | 5.6 | 6.7 | 6.0 | ... | 2.3 | 2.8 | 2.6 | ... |
| Sept. 13–Sept. 22 | 229.6 | 339.0 | 334.6 | ..... | 5.4 | 9.0 | 7.8 | ... | 2.3 | 2.6 | 2.3 | ... |
| Sept. 23–Oct. 1 | ..... | ..... | 204.0 | ..... | ... | ... | 5.0 | ... | ... | ... | 2.4 | ... |

In 1935 the first fishes caught between July 15 and July 24 had livers which averaged only 1.6 per cent of the dressed body weights. From this weight the liver percentage gradually rises until a peak of 2.4 per cent is reached in the August 24–September 2 interval. In the two ten-day which a high growth rate is observed (see above, page 2) the liver starts the season at 2.4 per cent, rises slightly in the next interval to 2.5 per cent, then drops sharply to 2.2 per cent (August 4–13). A second peak of 2.6 per cent is reached between September 3 and 12. As far as the records go for

1938 we see a situation similar to that of 1937 with the season starting at 2.0 per cent and then dropping to 1.9 per cent between August 4 and 13. It may be that in 1937 and 1938 the swordfishes met with an abundance of food-fishes farther south along the coast of Nova Scotia or in the Gulf of Maine and arrived off Louisburg in prime condition. In 1935 and 1936 the fish probably did not reach optimum feeding conditions until they had been several weeks offshore of Louisburg.

TABLE V

| Time Interval | 1935 | 1936 | 1937 | 1938 |
|---|---|---|---|---|
| July 15–July 24 | | | | |
| Observed | 4.6 | 5.1 | 5.7 | 5.7 |
| Expected | 6.1 | 6.1 | 5.5 | 6.0 |
| July 25–Aug. 3 | | | | |
| Observed | 4.4 | 5.8 | 5.9 | 5.2 |
| Expected | 4.7 | 6.0 | 5.4 | 5.6 |
| Aug. 4–Aug. 13 | | | | |
| Observed | 6.2 | 5.7 | 4.7 | 4.8 |
| Expected | 6.3 | 5.5 | 4.9 | 5.6 |
| Aug. 14–Aug. 23 | | | | |
| Observed | 6.1 | 6.0 | 5.6 | ... |
| Expected | 5.9 | 5.4 | 5.7 | ... |
| Aug. 24–Sept. 2 | | | | |
| Observed | 5.3 | 5.4 | 5.7 | ... |
| Expected | 5.0 | 5.0 | 5.5 | ... |
| Sept. 3–Sept. 12 | | | | |
| Observed | 5.6 | 6.7 | 6.0 | ... |
| Expected | 5.4 | 5.5 | 5.3 | ... |
| Sept. 13–Sept. 22 | | | | |
| Observed | 5.4 | 9.0 | 7.8 | ... |
| Expected | 5.3 | 7.1 | 7.0 | ... |
| Sept. 23–Oct. 1 | | | | |
| Observed | ... | ... | 5.0 | ... |
| Expected | ... | ... | 4.9 | ... |

The averages for all four years indicate a picture similar to that of the individual year, 1936, in which the swordfishes, arriving with depleted livers, reach a peak, presumably of glycogen or fat storage, between September 3 and September 12.

Were it not for the knowledge of the rate ("k") at which the liver normally grows with reference to the remainder of the body, we should be unable to tell whether or not the average liver weights in Table IV were merely the result of normal heterogonic growth. In Table V the observed and theoretical (or expected) liver weights in the several ten-day intervals are recorded.

Table VI conveniently lists the deviation in tenths of a pound and in ounces from the theoretical that is displayed by the observed average liver weights.

It is seen that the seasonal fluctuations noted in Table IV are not what would be expected if the normal heterogonic growth ratio was maintained. Thus the fluctuations noted are very probably the result of environmental factors (largely food conditions) which altered the normal heterogonic growth sufficiently to be measured. It is well known that the absolute size of the liver depends to a large degree on the food intake. Maximow and Bloom (1930) note (p. 548) that "the liver of the fasting animal is much smaller because of its decreased store of glycogen, etc., than that of the animal which is feeding regularly." This is also true of fat storage to an even greater degree. It seems as though the deviation of observed from theoretical liver weights in animals generally is a very good index to the food sources which have been available to them. It seems, also, that careful deductions may be made from such data which will explain the variations from season to season.

TABLE VI

| | 1935 | | 1936 | | 1937 | | 1938 | |
|---|---|---|---|---|---|---|---|---|
| Time Interval | Lbs. | Oz. | Lbs. | Oz. | Lbs. | Oz. | Lbs. | Oz. |
| July 15–July 24 | −1.5 | −24.0 | −1.0 | −16.0 | 0.2 | 3.2 | −0.3 | − 4.8 |
| July 25–Aug. 3 | −0.3 | − 4.8 | −0.2 | − 3.2 | 0.5 | 8.0 | −0.4 | − 6.4 |
| Aug. 4–Aug. 13 | −0.1 | − 1.6 | 0.2 | 3.2 | −0.2 | −3.2 | −0.8 | −12.8 |
| Aug. 14–Aug. 23 | 0.2 | 3.2 | 0.6 | 9.6 | −0.1 | −1.6 | ... | .... |
| Aug. 24–Sept. 2 | 0.3 | 4.8 | 0.4 | 6.4 | 0.2 | 3.2 | ... | .... |
| Sept. 3–Sept. 12 | 0.2 | 3.2 | 1.2 | 19.2 | 0.7 | 11.2 | ... | .... |
| Sept. 13–Sept. 22 | 0.1 | 1.6 | 1.9 | 30.4 | 0.8 | 12.8 | ... | .... |
| Sept. 23–Oct. 1 | ... | .... | ... | .... | 0.1 | 1.6 | ... | .... |

## SUMMARY

Nine hundred and nine swordfish (*Xiphias gladius*) body and liver weight records taken in 1935, 1936, 1937, 1938 were studied at some length and the following observations were made:

1. In the "dressing," or cleaning, process which is followed by swordfishermen in the Cape Breton, Nova Scotia region, about 25 per cent of the total weight is removed.
2. The observation of Raven and LaMonte (1936) that "the smaller the swordfish the greater its proportional liver weight" is more than amply substantiated in Table I.
3. The constant differential growth rate of the liver calculated from the group averages in Table I is 0.724, i.e., for each unit of body weight increase the liver weight increases by slightly more than seven-tenths of a unit.
4. In the sample population studied the deviation of actual (average) from theoretical (average) liver weight in each size class is never more than 0.6 of a pound (Table II).
5. Each individual year studied has a slightly different growth rate, except in 1937, when the rate was extremely high (0.858). This high rate may indicate an exceptionally fine food-year for the swordfishes, when the excess of food enabled the fish to maintain their general body growth rates as well as store large quantities of fat and/or glycogen.
6. The average body weight for the 909 specimens was 251 pounds (dressed) and the average liver weight, 5.7 pounds.
7. Arrangement of the data in ten-day intervals shows that as a rule the fish arrive off Cape Breton in the middle of July with sorely depleted livers, as much as 1.5 pounds below the expected size (Table VI). As food-fishes are met with, there is a steady rise in liver weight until in late August or early September their livers are as much as 1.9 pounds over the expected weight (1936). This peak is usually followed by a drop, presumably correlated with departure of the food-fishes. There may be a "threshold" in proportional liver weight at which time the swordfish leaves in search of the departed food-fishes.

In 1937, however, the swordfish apparently met the food-fishes south of Cape Breton, for when they arrived off Louisburg their livers were of more than the expected weight. In August the livers fell below theoretical weight and then in September rose once more.

The suggestion is made here that a very interesting story of the swordfishes' migrations might be worked out if we had similar data for other points along the North Atlantic coast. Also, that such data if taken from adjacent regions might reveal a "threshold level" (see paragraph 7 of summary) of the relative liver weight.

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