Re-evaluation of the length-weight relationship of Pacific halibut (*Hippoglossus stenolepis*)

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Abstract

Over the past 20 to 30 years, there has been a decrease in length-at-age of Pacific halibut (*Hippoglossus stenolepis*). Thought to be due to environmental factors and competition, it is unclear if there has been any effect on the length-weight relationship of halibut. The current length-weight relationship used by International Pacific Halibut Commission (IPHC) staff for stock assessment purposes was derived in 1926. Although revalidated in 1989, IPHC staff have identified the variability of the relationship in particular regions within the range of Pacific halibut, specifically in Alaska in some seasons. Halibut collected from IPHC Regulatory Area 3A were measured and weighed individually. The resulting length-weight equation was compared to data collected in 1989 (as direct comparison to data from 1926 was not possible) and was found to differ significantly.

Introduction

From the 1970s to present, Pacific halibut (*Hippoglossus stenolepis*) in U.S. and Canadian waters has experienced a reduction in length-at-age (Clark et al. 1999; IPHC 2011), which is often used as a growth parameter although it is controversial (see Mulligan and Leaman, 1992). Growth rates may vary due to both environmental factors, such as temperature fluctuations, prey quality, and population density, and direct human interaction, such as fishing. Hurst et al. (2010) studied the effect of temperature on the growth rates of larval and juvenile Pacific cod (*Gadus macrocephalus*) under controlled conditions. As temperature increased, each larval stage and juvenile growth rate of Pacific cod experienced an increase, although each stage responded with different magnitudes of increase. Prey quality has also been identified as an important factor regarding growth rates, in that prey with high energy content have been found to stimulate rapid growth in the predator (Bowen et al. 1995). Another factor that can affect growth rates is population density. Marshall and Frank (1999) measured the average growth of juvenile haddock (*Melanogrammus aeglefinus*) over several years. They found that at higher densities of adult haddock, juvenile growth was slower and resulted in smaller adults. Marshall and Frank (1999) cite Herrington (1944) as believing it to be due to the depletion of food resources by adult haddock, while juvenile haddock must compete for the remaining resources once the adults have departed. Alternatively, fisheries are generally size-selective due to fishing gear and techniques which often target specific size ranges and can affect natural growth rates of the target population through artificial selection (Hutchings and Fraser 2008; Matsumura et al. 2011). As Canadian and U.S. commercial halibut fisheries legally retain only individuals that are 81.3 cm in length and greater, one hypothesis for the current reduction in length-at-age is that the commercial fishery removes faster growing halibut and leaves fish that

[1] The IPHC provides training opportunities for undergraduate student interns and encourages them to prepare reports of their projects conducted at the IPHC. Reports by interns are included here with only minor editing.

grow slower, thereby reducing the probability of capture. IPHC staff do not believe this is the case as the long-term trend of the length-at-age relationship has varied, where it was higher in the 1970s than it was in the 1920s and 1990s (Clark et al. 1999), an indication that fisheries do not play a significant role in the current reduction. Factors affecting growth, particularly environmental factors, vary spatially and temporally (Arnekliev et al. 2006; Rilling and Houde 1999), and it is unclear if these factors have impacted not only the length-at-age relationship, but other features of Pacific halibut, such as weight-at-age and length-weight relationships.

As Pacific halibut length-at-age has decreased since the 1980s, a similar change has taken place with regards to the weight-at-age relationship, although it has not been explicitly studied as the weight-at-age is calculated using the length-weight relationship derived in 1926 from halibut captured in Masset, Canada (Fig.1; Clark 1992). The 1926 length-weight relationship currently used to estimate halibut biomass by the International Pacific Halibut Commission (IPHC) was re-evaluated during an otolith collection project conducted in 1989, and was determined to have been unchanged since its derivation (Clark 1992). Despite the revalidation of the 1926 length-weight relationship in 1992, IPHC staff has observed discrepancies between weight estimates using the 1926 length-weight relationship and dockside scale weights during IPHC charters, particularly in Alaska (IPHC unpub[2]). Since the length-weight relationship chart is applied as an area-wide and annual average from California to Alaska despite it being based on halibut collected in British Columbia, Canada, it will undoubtedly be slightly inaccurate when applied to any specific region or time. This may become problematic if the variation is considerable.

Changing weight-at-age relationships are a growing concern for halibut fishery managers. Since halibut length and not weight is collected on IPHC surveys, the length-weight relationship must be used to calculate the average weight-at-age. The IPHC calculates the estimated harvestable biomass based on catch and sampling data collected from commercial fisheries, which identifies the size and age classes of halibut that are susceptible to harvest practices. In the stock assessment, once the abundance of halibut that are susceptible to harvest has been estimated, the length-weight relationship is used to estimate the total biomass of fish susceptible to harvest. The yearly catch limit is calculated by estimating the level of sustainable catch that can be taken from the portion of the total biomass of halibut that is susceptible to exploitation. It is important that the differences in length and weight-at-age are accounted for in the assessment and the IPHC harvest policy. In this regard, a potential concern relates to the accuracy of the IPHC length-weight equation. Since the 1926 length-weight equation is still in use, if there has been a change in this relationship (i.e., that fish weight for a given length weigh is different than estimated from the formula) since the 1989 reassessment, then the IPHC may need to adjust calculations within the stock assessment to avoid potential overharvesting.

To examine whether there is evidence that the length-weight relationship may indeed have changed since 1989, and in turn since 1926, a small trial to re-evaluate the length-weight relationship in Alaskan waters was conducted. In this analysis, the length-weight relationship of halibut captured in one region of the northern Gulf of Alaska will be compared between the years 1989 and 2011.

[2]Eric Soderlund. Calculated weight versus fish ticket weight for 2010 IPHC Charters. 2320 W Commodore Way, Suite 300, Seattle WA 98199, 206-634-1838

Methods

To assess potential changes in the length-weight relationship since 1989, Pacific halibut were collected in IPHC regulatory Area 3A in the northern Gulf of Alaska (Fig. 2) aboard the *F/V Van Isle*, an IPHC-chartered commercial fishing vessel. Halibut were collected June 8-12 and again June 17-22 from IPHC sampling stations located between Seward and Kodiak (Table 1; Fig. 2). Six 1800-ft. skates of longline gear with an average of 100 circle hooks each were baited with #2 semi-bright chum salmon (*Oncorhynchus keta)*. At most, 4 stations were set per day in a north-south or east-west direction, starting no sooner than 0500 and were left to soak. After soaking for at least five hours, the skates were hauled and halibut were dressed prior to being measured. Dressing involved the removal of the gills and all internal organs. Fork length (FL) for each halibut was measured to the nearest centimeter. Three size classes were established as sampling units and included: halibut less than 80 cm FL, those between 80-110 cm FL, and those greater than 110 cm FL. Fish from the two smaller size classes were chosen randomly at a rate of 1 out of every 13, and were tagged with zip ties looped through the operculum, each with a unique identification number. Halibut larger than 110 cm were sampled at a rate of 2 out of every 3, and also tagged with zip ties with a unique identification number. Red zip ties were used to identify individual fish as O32 (i.e. halibut that are ≥ 82 cm FL and are legally retained and sold in the commercial fishery) which were sold to offset research costs, and blue zip ties were used to identify U32 fish (i.e. halibut < 82 cm FL that cannot legally be retained in the commercial fishery). Red and blue zip ties had different number sequences to reduce the chance of mismatching fish FL and weight. Once in port, the tagged halibut were weighed head-on, dressed, and included ice and slime, using certified processing plant scales. In early June, halibut were weighed to the nearest 0.5 lbs. at Icicle Seafoods Inc., Seward, AK, and fish collected in mid-June were measured to the nearest 0.01 lbs. at Island Seafoods, Kodiak, AK.

To compare the 2011 length-weight relationship to the 1989 length-weight relationship for halibut located only in stat areas 240, 250, 260 and 270 in Area 3A[3] (Fig. 2), 2011 halibut weights were transformed into net weight by multiplying by 0.882 to account for the weight of the head (10%) and ice and slime (2%). Both samples were analyzed collectively by fitting two models (Le Cren 1951) to the dataset. The first model described both samples as one using the following equation:

$$W = aL^{b}$$

where W is the net weight in pounds (head off, dressed, without ice and slime) and L is the fork length in centimeters. Parameters *a* and *b* were estimated by minimizing the sum of squares. The second model was a multiple non-linear model which allowed for both samples to be described simultaneously, such that

$$W = (a+\alpha D)\, L^{(b+\beta D)}$$

where α and β are the difference between 1989 and 2011 parameters, *a* and *b*, respectively, and D is a dummy variable:

$$D = \begin{cases} 0 \text{ if halibut is from 1989 sample} \\ 1 \text{ if halibut is from 2011 sample} \end{cases}$$

[3] Larsen, M. J., and St. Pierre, G. Unpub. Setline halibut surveys: 1989 and 1992 otolith collections. Technical Report Draft International Pacific Halibut Commission. Seattle, WA

The two models were fitted using non-linear least squares, and an *F*-test was used to determine which of the two models better described the sample data. Finally, the length-weight equation derived from the 2011 data was compared to both the 1926 length-weight equation and the equation derived from the subsample of the 1989 data to compare differences in predicted weight over a range of fork lengths. The 2011 length-weight data could not be directly compared to 1926 data as the length and weight of halibut from Masset, BC, were not available.

Results

To reassess the length-weight relationship from 1989, a total of 193 fish were sampled in 2011, and 1949 fish from the 1989 sample (which included only halibut caught in the aforementioned statistical areas) were used for comparison.

The test comparing the two models provided strong evidence that the models parameters for the 2011 data differ from those for the 1989 data, i.e., that the length-weight relationships are different ($F_{2,\,2138}$= 5.407, p=0.005). Comparing the estimated curves for 1989 and 2011 data, weights were consistently lower at given lengths (Fig. 2). The 2011 length-weight equation was estimated as

$$W_N = (9.321x10^{-6})\ L^{3.16}$$

in comparison to the 1926 equation, and the 1989 equation generated in this study

$$1926\quad W_N = (6.921x10^{-6})\ L^{3.24}$$
$$1989\quad W_N = (1.290x10^{-5})\ L^{3.11}$$

where the 1926 length-weight relationship is the current conversion used by IPHC staff. Although Clark (1992) determined that there was no significant difference between the 1989 equation and 1926 equation (using a different subset of the 1989 samples), the two equations differ in predicted weight when compared to the 2011 length-weight equation. In general, the smaller size classes reveal a greater percent difference between 2011 and 1989, while larger size classes exhibit a greater percent difference between 2011 and 1926 (Fig. 3).

Conclusions

Since the 1970s, the weight-at-age of Pacific halibut has been decreasing (Clark and Hare 2002) not only due to the reduction in length-at-age (Clark et al. 1999), but likely also due to the decline in the length-weight relationship over time, as demonstrated in this study. Although this study illustrated a significant difference between the length-weight relationship derived in 1989 and that derived in 2011, it is equally important to consider differences between the 1926 length-weight relationship currently used and the one described in this study. This is particularly vital as the percent difference in estimated weight increases in magnitude as fork length increases when comparing the 2011 equation and the current 1926 equation, whereas the opposite is true between the 2011 equation and the 1989 equation (Fig. 3). As the 1926 length-weight equation is currently used and exhibits a greater magnitude of percent difference in calculated weight for O32 halibut, it is more useful to compare the 2011 equation to the 1926 equation. This comparison would reveal if there is a great enough difference in estimated weight for longer fish to warrant further study regarding the length-weight relationship throughout the range of Pacific halibut. Regardless, this study provides evidence for a change in the length-weight relationship of Pacific halibut, at least in the region covered by the samples, although this trend is difficult to explain. Clark et al. (1999) suggest several hypotheses to explain the overall reduction in weight-at-age, which include prey switching, increases in other marine species populations, and climate regime shifts.

A change in the quality of prey is thought to be a potential reason for the observed trend for the length-weight relationship. A study of Pacific halibut diets in the Eastern Bering Sea by Livingston et al. (1993) indicated that between 1987 and 1989 the top prey items consumed by halibut were walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), snow crab (*Chionoecetes opilio*) and Tanner crab (*Chionoecetes bairdi*). Since this study, walleye Pollock populations in the Eastern Bering Sea have remained relatively stable (Ianelli et al. 2010), while Pacific cod populations experienced a decrease in biomass (Thompson et al. 2010), and both snow crab and Tanner crab have experienced declines (North Pacific Fishery Management Council 2010) which may have caused a shift in diets of Pacific halibut. Dietary shifts may cause halibut to consume a higher abundance of less favorable prey items. These prey items may be less energetically beneficial, decreasing the overall halibut length-weight relationship. Although the reasons for prey switching are not well studied, it may be due to changes in abundance of prey species or increased competition.

Pacific halibut may be experiencing greater intraspecific competition, or greater direct or indirect interspecific competition with other flatfish species, such as arrowtooth flounder (*Atheresthes stomias*) (ADF&G 2011). Not only has the halibut population been increasing, most notably for smaller size classes (Hare 2010), arrowtooth flounder populations in Alaska have also been increasing (Anderson and Piatt 1999). Higher numbers of Pacific halibut may be causing growth rates to decrease due to density-dependence, while larger populations of competing species may cause behavioral shifts in halibut that result in a greater expenditure of energy or reduced ability to obtain food resources.

Expanding flatfish populations and fluctuating walleye pollock and Pacific herring populations have been linked to climate regime shifts (Anderson and Piatt 1999; Brown 2002; Dorn et al. 2010; Francis et al. 1998), such as those caused by the Pacific Decadal Oscillation (PDO) during 1976-1977 (Clark et al. 1999). The climate shift during 1976-1977 is thought to have caused not only shifts in marine communities (Anderson and Piatt 1999), but also changes in growth patterns of Pacific halibut (Clark et al. 1999). Studies show that not all regions of the Pacific Ocean were affected similarly (Francis et al. 1998). In particular, Clark et al. (1999) found that halibut located in British Columbia did not experience the same degree of reduction in length-at-age as halibut located in Alaska. As this study analyzed fish located only in the Gulf of Alaska, it is highly recommended that fish from the Bering Sea, western Alaska, British Columbia, Washington, and Oregon be analyzed by appropriate groupings to identify regional differences in length-weight relationships. If halibut these relationships vary significantly among areas, it may be more appropriate to incorporate regional differences in future stock assessments.

This study has not investigated whether regional differences in length-weight relationships and an increase in the difference between estimated weights using the 2011 length-weight equation and the 1926 length-weight equation would have a substantial impact on halibut stock assessment and quota allocation. Since O32 halibut are experiencing a greater deviation from the equation derived in 1926, the weight-at-length relationship as described in this study may have significant effects on harvestable biomass as currently estimated by IPHC staff. However, the largest differences between these two relationships are for larger fish (>120 cm) which are less abundant in the population at present, than in 1926. Further research identifying the sensitivity of the stock assessment and quota allocation process to length-weight relationship changes would help to identify if further research is necessary to further investigate regional differences in halibut growth rates.

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Table 1. Numbers of halibut caught each day at each survey station during the 2011 length/ weight study period aboard the IPHC survey vessel *F/V Van Isle*.

Date	n	Survey Station Number
6/8/2011	12	4188, 4192
6/9/2011	34	4170, 4171, 4179
6/10/2011	13	4161, 4169
6/11/2011	8	4155, 4156, 4163
6/12/2011	10	4157, 4164, 4165
6/17/2011	35	4152, 4215, 4216, 4222
6/18/2011	30	4200, 4201, 4207, 4208
6/19/2011	28	4202, 4203, 4209, 4210
6/20/2011	15	4198, 4199, 4260
6/21/2011	6	4250, 4251, 4259
6/22/2011	2	4245
Total	193	

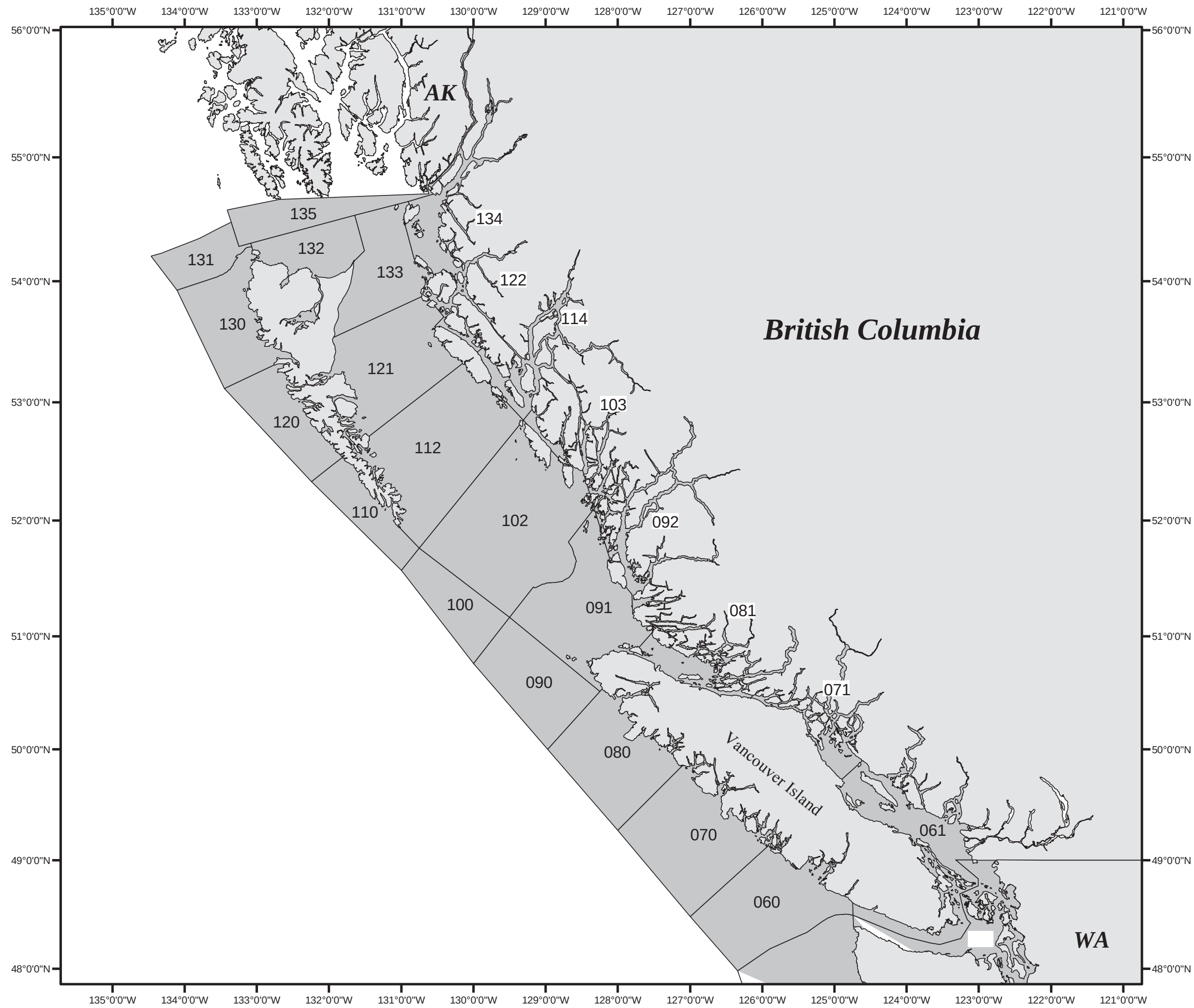

Figure 1. Map of British Columbia. Red circle indicates generalized region where halibut data from 1926 was likely to be collected from.

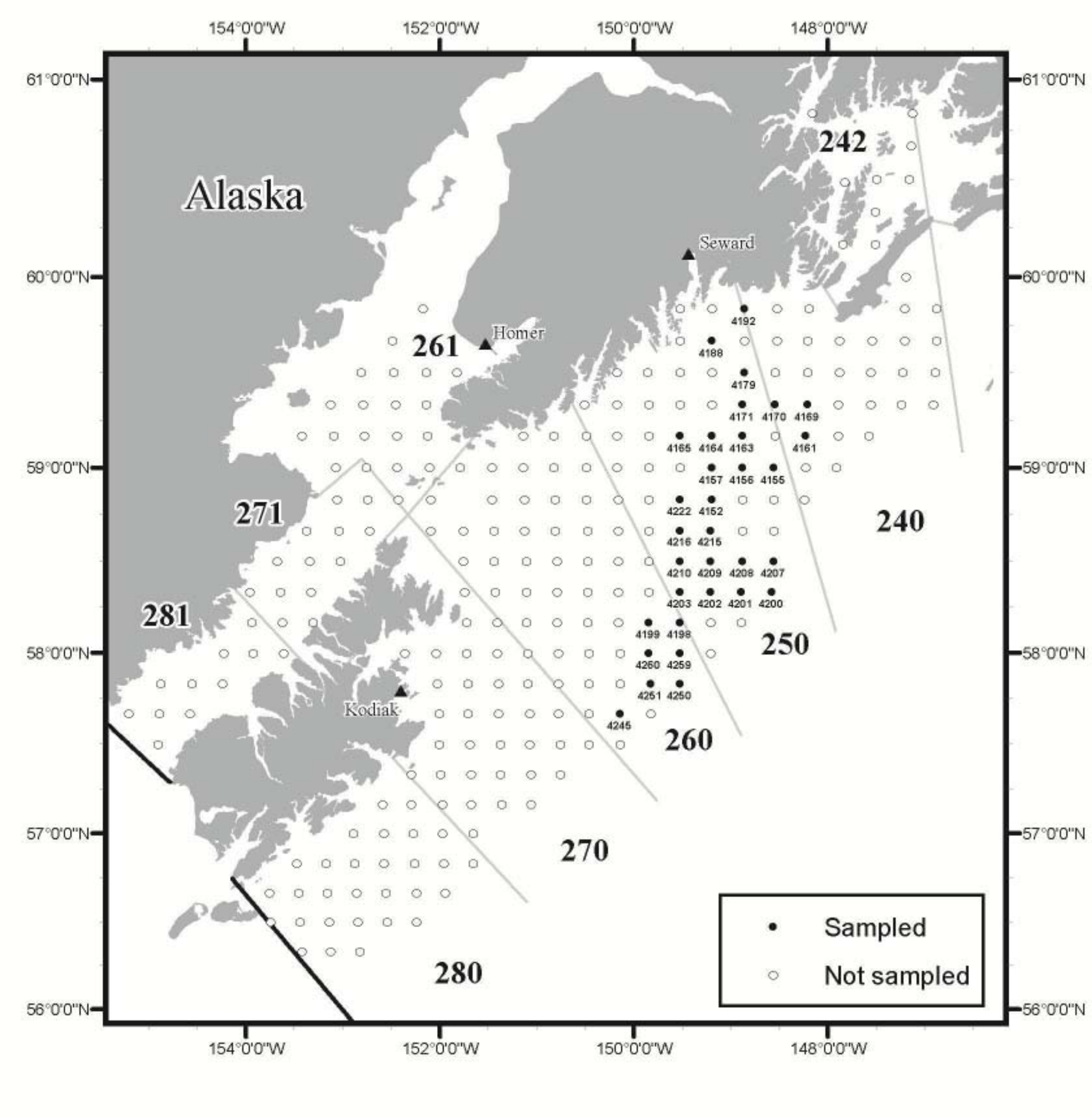

Figure 2. Map of the Gulf of Alaska sectioned by IPHC Statistical Areas overlaying IPHC Regulatory Area stations. Only stations sampled are labeled with the station number.

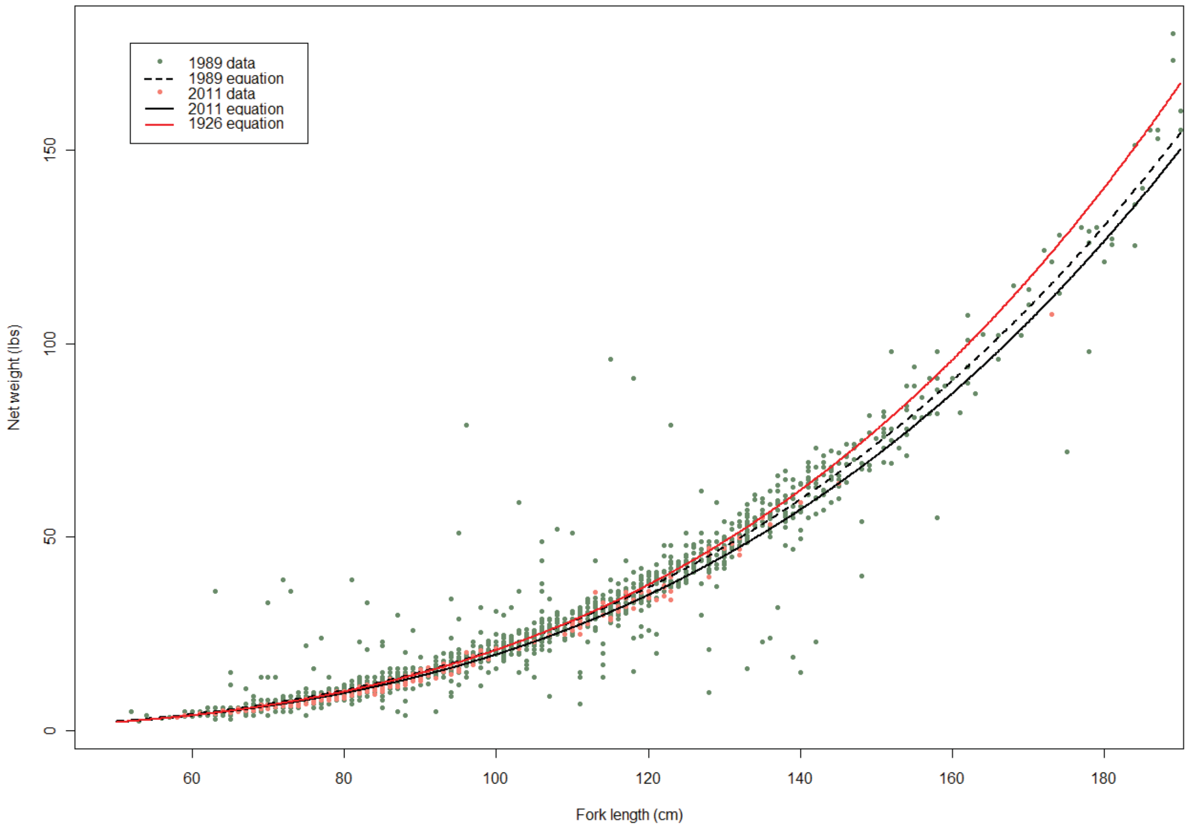

Figure 3. Length-weight relationship for Pacific halibut (*Hippoglossus stenolepis*) in 2011 and 1989 as raw data (a, $F_{2, 2138}$= 5.407, p=0.005), and with associated trend lines. The 1926 length-weight equation is included for comparison.

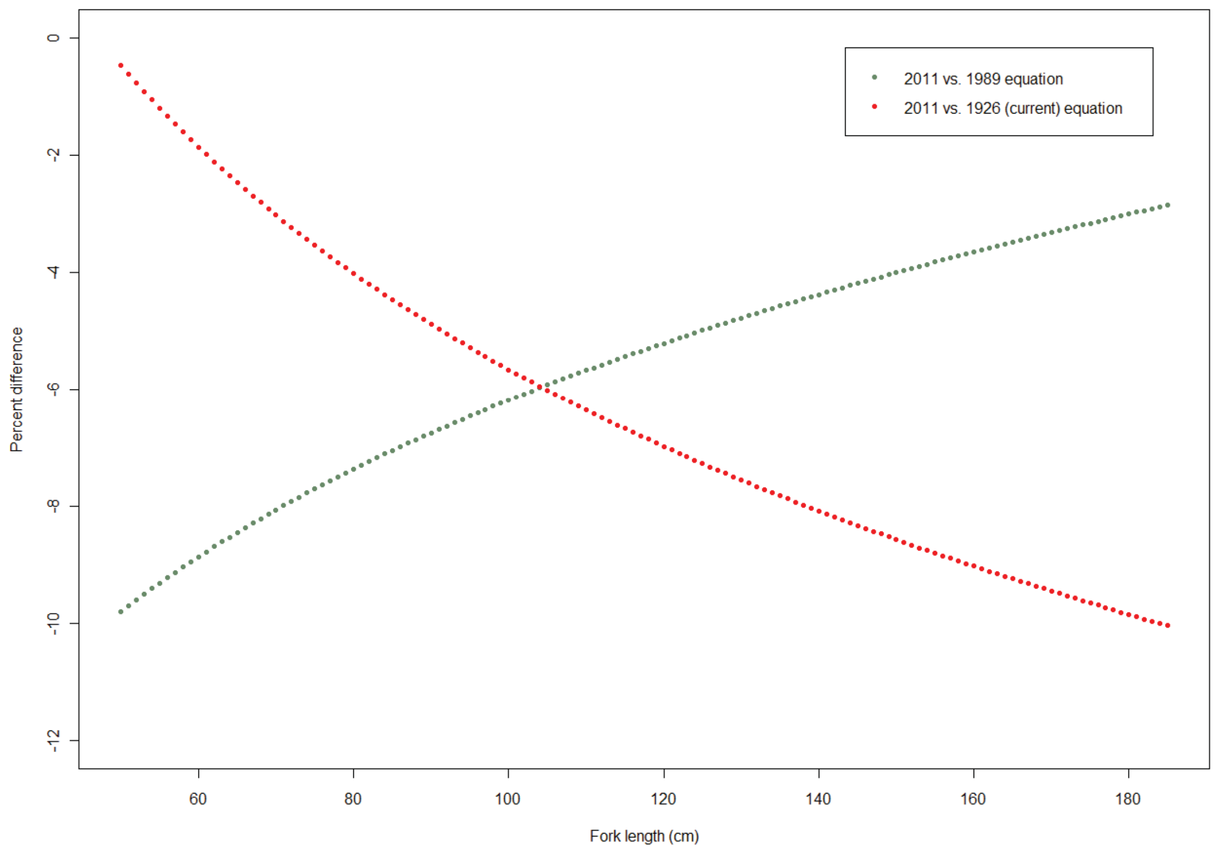

Figure 4. The percent difference between weights estimated using 2011 length-weight equation ($W_N = 9.321x10^{-6} * L^{3.16}$) as compared to the current length-weight equation ($W_N = 6.921x10^{-6} * L^{3.24}$) and the length-weight equation derived from 1989 data ($W_N = 1.290x10^{-5} * L^{3.11}$). More negative values indicate greater estimated weights by the 1926 or 1989 length-weight equation as compared to the 2011 length-weight equation.