Parameterization of a model for Greenlandic halibut

1. Introduction.

We have constructed a number of empirical models for the Greenlandic halibut (from now on only halibut) fishery at the west coast of Greenland. To construct these models, data have been collected and the parameters in a number of functions have been estimated. This paper contains documentation for our empirical work on the halibut fishery. Specifically, we present all data that have been collected and the estimation of the parameters in the relevant functions.

2. Data and relevant information.

2.1. The fishing industry.

From personal communication with Hilmar Ogmundsson based on Ogmundsson (2019), we have obtained information about various economic indicators for the primary fishing sector in all parts of Greenland. Table 1 summarizes some of these indicators for the period between 2010 and 2015.

Table 1: Economic indicator for the primary fishing industry, 2010-2015.

From Table 1, we see that the revenue (without subsidies), accounting costs, and accounting profit in the primary fisheries sector are fluctuating (with a tendency to increase). It should be noted that the accounting costs in Table 1 include fisheries taxes and that it can be argued that these transfers ought to be excluded in economic indicators.

However, not only the primary fishing sector is important for Greenland but also secondary fisheries-related industries. From Ogmundsson and Haraldson (2017), we have information about economic indicators for the whole fishing industry. Table 2 shows some of these indicators for the period between 2010 and 2015.

Table 2: Economic indicators for the whole fishing industry, 2010-2015.

From Table 2, we observe that the economic indicators, represented by the revenue, accounting costs, and accounting profits, have tended to increase. Two issues in relation to the accounting costs in Table 2 should be noted. First, the accounting costs include production-related taxes, and it is to be argued that these ought to be excluded. Second, part of the revenue earned by the primary fishery represents a part of the accounting costs in the secondary fisheries-related industry, and this is reflected in the revenue and accounting costs in Table 2.

2.2. Regulation of vessels from Greenland.

The fishing territory in Greenland is placed within a 200 nautical miles limit from the coast and can be decomposed into a west and east coast. Furthermore, the commercial fisheries in both areas consist of high seas and coastal fisheries. The high seas fisheries occur more than 3 nautical miles from the coast while the coastal fisheries take place within a 3 nautical miles limit.[1] High seas fisheries are mainly undertaken by large production vessels while small vessels or boats conduct coastal fisheries.

[1] There are some exemptions from this general rule. As an example, a limited amount of small vessels can fish outside the 3 nautical miles limit.

For both the west and east coast, a total allowable catch (TAC) is fixed each year for the most important fish species based on biological recommendations. For both areas, the TAC is further allocated as total quotas to the high seas and coastal vessels and then the total high seas quota is distributed between vessels from Greenland and foreign vessels. Statistics Greenland (2020) contains information about the total high seas quota distributed to vessels from Greenland at the west and east coast, and information about these quotas for the period between 2013 and 2016 is provided in Table 3.

Table 3: High seas quotas at the west and east coast, 2013-2016.

From Table 3, we see that the total high seas shrimp quota at the west coast decreased between 2013 and 2015 but that the quota increased in 2016. The total high seas cod quota at the west coast has been constant while the total halibut high seas quota has increased between 2014 and 2015. The high seas quota for other fish species at the west coast has increased a lot between 2013 and 2015, and this is due to a dramatic increase in the mackerel quota (see Statistics Greenland, 2020). At the east coast, the total high seas quota for harvesting shrimp and halibut has decreased. It should be noted that a part of the total cod quota can be used at both the east and west coast.

Statistics Greenland (2020) also contains information about the total coastal quotas, and an overview of these quotas at the west coast can be found in Table 4.

Table 4: Coastal quotas at the west coast, 2013-2016.

From Table 4, we see that the total coastal shrimp quota at the west coast has decreased between 2013 and 2015 and increased in 2016 while the total coastal cod quota has increased. The total quota for harvesting other fish species at the west coast has been fluctuating. Regarding the total coastal halibut quota at the west coast, we must distinguish between vessels above 6 meters and boats below 6 meters. For vessels above 6 meters, the total halibut quota has increased between 2014 and 2015 while the total halibut quota for boats below 6 meters has increased over the whole time period.

Individual vessels are regulated by licenses and quotas. A license is required to undertake commercial fisheries for all fish species in Greenland, and two types of licenses are used: a. Time-limited licenses; b. Time-unlimited licenses. Time-limited licenses are normally issued for one year and may contain a maximum harvest. Time-unlimited licenses normally contain a maximum harvest. In the coastal fishery targeting halibut in the Disko Bay, Uummannaq, and Upernavik, time-limited licenses without a maximum harvest are used for boats below 6 meters while time-unlimited licenses with a maximum harvest are used for vessels above 6 meters. Furthermore, time-limited licenses without a maximum harvest are used in the high seas halibut fisheries while time-unlimited licenses with a maximum harvest are used in all fishery targeting shrimp. Furthermore, individual transferable quotas (ITQs) are used to regulate part of the shrimp fishery. More importantly, an ITQ system was also introduced for the coastal fishery for vessels above 6 meters targeting halibut in the Disko Bay, Uummannaq, and Upernavik in 2012.

2.3. International fishing agreements.

As mentioned in section 2.2., a part of the high seas quota is allocated to foreign vessels according to international fishing agreements. The fishing agreement with the EU is very important for Greenland, and this agreement was entered for the first time in 1985. The agreement is enforced through protocols that cover a number of years. According to the fisheries agreement with the EU, Greenland obtains free access for fish products to the markets in the EU. Furthermore, Greenland receives economic compensation for providing vessels from the EU with access to the territory of Greenland. At present, a protocol for 2016-2020 determines the high seas quota distributed to the EU while the previous protocol covered the period between 2013 and 2016. Statistics Greenland (2020) contains information about the total quota allocated to vessels from the EU at the east and west coast, and Table 5 summarizes this information.

Table 5: High seas quota to vessels from the EU at the west and east coast, 2013-2016.

From Table 5, we see that under the protocol for 2013-2016 harvesting shrimp and halibut at the east coast is important for vessels from the EU. At the west coast, shrimp, and halibut are also important species, but the total shrimp and halibut quota at the east coast is approximately two times higher than at the west coast. Part of the quota allocated to the EU can be harvested at both the east and west coast, and here other fish species are very important for the protocol from 2013 to2016. This is due to a very large solder quota that can be harvested in both territories (see Statistics Greenland, 2020). However, in the protocol for 2016-2020, the total solder quota has been decreased dramatically, and an identical development has occurred for the shrimp quota at the east coast (see Statistics Greenland, 2020). The quota for harvesting other species in both territories is approximately unchanged with the protocol for 2016-2020.

Regarding fisheries agreements with other countries, Greenland has entered bilateral agreements with several fishing nations. These agreements provide vessels from Greenland with access to the fishing areas of other nations while other fishing nations obtain access to the areas in Greenland. These bilateral agreements are very complicated and can be difficult to summarize, but Statistics Greenland (2020) contains information about the total quotas distributed to other fishing nations. The total halibut quotas allocated to Russia, Norway, and the Faroe Islands for fishing halibut at the west coast for 2013-2016 are summarized in Table 6.

Table 6: High seas halibut quota to vessels from other countries at the west coast, 2013-2016.

From Table 6, we see that the total halibut quotas allocated to Russia, the Faroe Islands, and Norway at the west coast are approximately constant for the whole time period. This reflects the fact that bilateral agreements between independent fishing nations are normally formulated as a share of a biological recommended TAC that each nation obtains for a longer time period.

2.4. Landing obligation.

In Greenland, a landing obligation has been introduced in order to secure land-based employment. For high seas vessels targeting halibut at the west coast, 25 % of the landings should be delivered for land-based processing, and, in addition, 1500 tons of the harvest should be supplied for filtering. For the coastal vessels at both the west and east coast, the main rule is that the landing obligation covers the whole harvest of all fish species.[2] Ogmundsson and Haraldson (2017) contains information on the amount of fish delivered for land-based processing by both high seas and coastal vessels from Greenland at the west and east coast, and this information is summarized in Table 7 for the period between 2013 and 2015.

[2] However, some coastal vessels have an exemption from this rule in the sense that they can process 75 % of their own harvest.

Table 7: Quantity of fish delivered for land-based processing at the west and east coast, 2013-2015.

From Table 7, we see that the amount of shrimp delivered for land-based processing has decreased and that the same has occurred for stone chunks. The amount of cod has increased dramatically while the amount of halibut has increased between 2013 and 2014 but decreased between 2014 and 2015. The amount delivered of other fish species is approximately constant.

From personal communication with Hilmar Ogmundsson based on Ogmundsson (2019), we also have information about the quantity of fish produced by land-based processing factories. Table 8 shows the calculated quantity of shrimp, halibut, and cod supplied by all land-based factories between 2013 and 2015.

Table 8: Quantity of fish produced by land-based processing factories, 2013-2015.

From Table 8, we see that the quantity of shrimp produced by land-based factories has decreased while the quantity of cod has increased. The quantity of halibut is approximately constant. Furthermore, by comparing the numbers in Tables 7 and 8, we see that for obvious reasons the production of shrimp, halibut, and cod by land-based factories is lower than the input of these species from primary fisheries.

2.5. High seas vessels.

As mentioned in section 2.2, this fishery is regulated with time-limited licenses without a maximum harvest. The high seas vessels targeting halibut at the west coast perform this in a mixed fishery with cod and redfish, and the contribution of each of these species to the industry revenue and costs is not straightforward to identify. Furthermore, the vessels are production trawlers that harvest fish and do processing on board the vessel, but as mentioned above, a landing obligation implies that 25 % of the harvest of halibut must be delivered for land-based processing.

Ogmundsson and Haraldson (2017) have collected data on the industry revenue, costs, and harvest from tax authorities. Since Ogmundsson and Haraldson (2017) use tax information, the industry costs represent accounting information, but ideally, we should have obtained a measure for the opportunity costs. However, from the accounting costs in Ogmundsson and Haraldson (2017), we are not able to obtain a measure for the opportunity costs. Therefore, we have chosen to use the industry revenue, accounting costs, and harvest from Ogmundsson and Haraldson (2017) directly. Also, it should be noted that the industry revenue and accounting costs in Ogmundsson and Haraldson (2017) cover all fish species for vessels targeting halibut. The relevant information is summarized in Table 9 for the period between 2013 and 2016.

Table 9: Economic indicators for high sea vessels targeting halibut at the west coast, 2013-2015.

From Table 9, we see that 4 production trawlers participated in the high seas fishery targeting halibut at the west coast between 2013 and 2015. The industry revenue has increased in the whole time period, and this can be partly due to a huge increase in the international (export) halibut prices (see Statistics Greenland, 2010). The industry accounting costs (with and without taxes or depreciation) have also increased over the whole time period. One explanation for this fact is that employees on fishing vessels may be remunerated according to a share of revenue rule, and since the revenue has increased, the remuneration to employees has also increased. A potential problem with using the information in Table 9 in our study is that the data is collected from tax authorities while Statistics

Greenland (2020) is used as our data source for the quotas and other economic indicators. To investigate whether different data sources pose a problem, we can use the quotas from Table 3 and the harvest from Table 9 to calculate a quota utilization. From Table 9, we see that the calculated halibut and cod quota utilization are high, implying that using data collected from tax authorities does not pose a problem.

2.6. Coastal vessels above 6 meters.

The coastal fishery with vessels above 6 meters targeting halibut at the west coast mainly occurs in a mixed fishery with cod, and this fishery is regulated with time-unlimited licenses with a maximum harvest and ITQs. Licenses and quotas of these fishing vessels can be decomposed into four areas: a. The Disko Bay; b. Uummannaq; c. Upernavik; d. Other parts at the west coast of Greenland. Ogmundsson and Haraldson (2017) contains information on economic indicators at industry level for vessels above 6 meters, but for high seas vessels accounting costs (and not opportunity costs) are identified, so we have also chosen to use this cost measure for vessels above 6 meters. The industry data for vessels above 6 meters is presented in Table 10 for the period between 2013 and 2015.

Table 10: Economic indicators for coastal vessels above 6 meters targeting halibut at the west coast, 2013-2015.

From Table 10, we see that between 32 and 79 vessels participated in the fishery at the west coast between 2013 and 2015. The industry revenue has increased between 2013 and 2014 but has decreased between 2014 and 2015, and the industry accounting costs have followed the same pattern. However, it should be noted that taxes are not included in the cost observations in Table 10. This is due to the fact that taxes on coastal vessels above 6 meters were introduced for the first time in 2016 while our data covers the period between 2013 and 2015. Finally, by looking at the halibut quota utilization in Table 10, we can conclude that using data from tax authorities does not pose a problem for our study.

2.7. Coastal boats below 6 meters.

The boats below 6 meters targeting halibut in the coastal area are regulated with time-unlimited licenses without a maximum harvest. The boats may harvest halibut in a mixed fishery with cod, but often they have a very limited sailing capacity, so they are dependent on local trading posts. Ogmundsson and Haraldson (2017) summarize economic indicators at an industry level for coastal boats below 6 meters, but as above we use accounting costs (and not opportunity costs). Despite this fact, we choose to use the information in Ogmundsson and Haraldson (2017) directly, and Table 11 contains the relevant indicators for the period between 2013 and 2015.

Table 11: Economic indicators for coastal boats below 6 meters targeting halibut at the west coast, 2013-2015

From Table 11, we see that a huge number of boats participated in the fishery and that there is an increase in the number of boats between 2013 and 2015. The industry harvest of both cod and halibut has increased, and the industry revenue and accounting costs (both with and without depreciation) follow the same pattern. Finally, as for vessels above 6 meters, no taxes are included in Table 11 because no harvest fees were used in the period between 2013 and 2015. Finally, from Table 11 we can see that the halibut quota utilization is large, so using information from tax authorities does not pose a problem.

2.8. Biological information with a common fish stock.

Since 1997, the Northwest Atlantic Fisheries Organization (NAFO) has estimated the halibut stock size and harvest in an area that almost corresponds to the west coast of Greenland. We have obtained relevant information about the halibut stock size and harvest from personal communication with Margaret A. Treble based on NAFO (2019). The measure for the halibut stock size includes recruitments and can be defined as the total halibut biomass while the halibut harvest are the catches by all fishing nations in the relevant area. The measure for the halibut stock size is collected on 1 October each year while the harvest is measured on 31 December. Thus, if we assume an unchanged halibut stock size between 1 October and 31 December each year, we can calculate a time series for the natural growth of halibut as:

$$G_t = x_t - x_{t-1} + h_t \qquad (1)$$

where G_t is the natural growth of halibut (in a given year), x_t is the halibut stock size, x_{t-1} is the halibut stock size in the previous year, and h_t is the halibut harvest by all fishing nations. Table 12 shows the time series for the halibut stock size, harvest, and natural growth at the west coast between 1997 and 2017.

Table 12: Stock size, harvest, and growth of halibut at the west coast, 1997-2017.

The halibut stock size in Table 12 tended to increase (with fluctuations) until 2011 while it tended to decrease after 2011. The halibut harvest by all fishing nations increased over the whole time period. From Table 12, we also see that the natural growth of halibut fluctuated a lot over the whole time period. A potential problem for our study is that the area for measuring the halibut stock size and harvest in Table 12 differs from the area for which the halibut quota is calculated. Therefore, we calculate the halibut quota utilization by using the halibut quotas from sections 2.2 and 2.3. From the halibut quota utilization, we see that the harvest by all fishing nations, obtained from personal communication with Margaret A. Treble based on NAFO (2019), constitutes between 76 % and 86 % of the total halibut quotas as reported by Statistics Greenland (2020). Thus, the halibut harvest in Table 12 seems to be consistent with the total halibut quotas from Statistics Greenland (2020).

2.9. Biological information with two separate fish stocks.

Now we assume that halibut in the high seas and coastal areas constitute two different (sub) populations. Thus, we must distribute the halibut stock size and harvest from Table 12 on a high sea and coastal halibut population. Regarding the halibut stock size, we have information about the relative distribution of one-year-old halibut in the Disko Bay between the coastal and high seas area for the period between 1992 and 2011 from personal communication with Ole A. Jorgensen based on Jorgensen (2013). We use these numbers to distribute the halibut stock size from Table 12 on a high seas and coastal stock size for 1997-2011. For the period between 2012 and 2017, we use the average halibut distribution for 1992 and 2011 given as 62 % in the high seas area and 38 % in the coastal area. To distribute the halibut harvest to the high seas and coastal area, we use the halibut quotas from 2015 reported in sections 2.2 and 2.3, and in doing so, we assume that all foreign vessels conduct high seas fisheries. Thus, the share allocated to high seas harvest reflects the high seas halibut quota to vessels from Greenland, the EU and other fishing nation in 2015. Finally, we operate with a separate high seas and coastal natural growth of halibut, and for both the high seas and coastal areas, (1) is used to calculate time series for the growth.

Thus, we can identify a separate time series for the high seas and coastal halibut stock size, harvest, and natural growth at the west coast for the period between 1997 and 2017 which is summarized in Table 13.

Table 13: High seas and coastal stock size, harvest, and growth of halibut at the west coast, 1997-2017.

The high seas and coastal halibut stock size and harvest follow the development in Table 12 while the high seas and coastal natural growth fluctuate a lot.

3. Functional forms and parameter estimates.

3.1. Common fish stock.

3.1.1. Natural growth function.

A logistic growth function fulfills the assumptions about the derivations from the theoretical model, and this function is given by:

$$F(x) = rx(1 - \frac{x}{K}) \tag{2}$$

where r is the intrinsic growth rate and K is the carrying capacity.

To estimate a growth function for halibut, we can follow at least two strategies. First, we can use the observations for the halibut stock size and natural growth from Table 12 and estimate (2) directly. When doing so by using ordinary least square (OLS), we obtain a u-shaped (not inverse u-shaped) growth function for halibut, and this is inconsistent with conventional fisheries economics. However, introducing restrictions on the carrying capacity may change the result. Second, as in the theoretical model, we can assume that the halibut fish stock is in a steady-state equilibrium in each year the data set covers, and thereby we can estimate the resource restriction for halibut directly. Specifically, by using the resource restriction and inserting (2), we can estimate the following equation:

$$h_H + h_C + \beta h_H = rx - \frac{rx^2}{K} \tag{3}$$

From Table 12, we have information about the total halibut harvest by all countries ($h_H + h_C + \beta h_H$) and halibut stock size (x) so (3) can be estimated with OLS. As stated above, a problem with this method is that we assume that the halibut stock size is in a steady-state equilibrium for each year the data set covers (apart from stochastic variation). However, a plot of the halibut stock sizes in Table 12 indicates that the stock size fluctuates around a mean of approximately 75.000 tons. Thus, the assumption about a steady-state equilibrium for the halibut stock size holds as a rough approximation.

For estimation purposes, we transform (3) into the following equation:

$$h = ax - bx^2 \qquad (4)$$

Where h is the aggregated halibut harvest while a and b are estimated parameters. By comparing (3) and (4), we get that:

$$a = r \qquad (5)$$

$$K = \frac{r}{b} \qquad (6)$$

Thus, we estimate (4) with OLS and then use (5) and (6) to calculate the intrinsic growth rate and carrying capacity. The estimation results are shown in Table 14.

Table 14: Natural growth function.

From Table 14, we have that both *r* and *b* are insignificant but have the expected sign. For *K*, we cannot investigate whether the parameter is significant because the carrying capacity is calculated by using *r* and *b* as stated in (6). R^2 is reasonably high despite the fact that both estimated parameters are insignificant while the Durbin-Watson test value is 0.178. With a critical value of 0.810, we may have a problem with positive serial correlation, but in fisheries economics, it is not common practice to try to correct for serial correlation when estimating a growth function. As always, the estimated parameter values in Table 14 are subject to statistical uncertainty, and the size of this uncertainty can be seen from the standard errors of *r* and *K*. To investigate the implications of statistical uncertainty, we will conduct sensitivity analyses. A normal procedure for doing this would be to vary the parameter values with 1.96 times the standard derivation, but this approach yields a negative value of *r* and *b*. For *r*, we, therefore, choose to vary this parameter with +/- 50 %, and an upper and lower bound generated by this variation is reported in Table 14. To secure consistency, we also vary *b* by +/- 50 % and then we assume that all parameter variation in *b* is due to variation in *K*. Thus, we can use (6) to calculate upper and lower bounds for *K* that are reported in Table 14.

3.1.2. High seas cost function.

A high seas industry cost function that fulfills the assumptions about the derivatives from the theoretical model is:

$$C_H(h_H, x) = c_H \frac{{h_H}^2}{x} \qquad (7)$$

where c_H is a high seas cost parameter, h_H is the high seas halibut harvest, x is the halibut stock size, and $C_H(h_H, x)$ is the total high seas industry cost of fishing halibut.

To identify the high seas cost parameter in (7), we only have information about the total high seas industry costs and harvest for three years (2013-2015) from Table 9, so we cannot estimate the parameter statistically. Instead, we must use one observation for the total high seas cost, harvest, and stock size to calculate the high seas cost parameter, and by using (7), this can be done in the following way:

$$c_H = \frac{C_H(h_H, x)x}{{h_H}^2} \qquad (8)$$

However, the total high seas industry costs in Table 9 cover the harvest of all fish species, so from this information, we will find the total high seas costs of harvesting halibut. The steps undertaken for performing this task are summarized in Table 15.

Table 15: High seas cost parameter.

In Table 15, we have inserted the total high seas industry costs of harvesting all fish species for 2013-2015 from Table 9, and from this, we must find the total high seas costs of harvesting halibut. One solution is to use the halibut harvest shares, which can be calculated from Table 9, to identify the total high seas cost of harvesting halibut. However, from (8), the high seas halibut harvest is used to calculate the high seas cost parameter, so using halibut harvest shares is not a good idea. Instead, we will use the halibut quota shares at the west coast that can be calculated from Table 3. From Table 9, we know that the high seas vessels harvest halibut in a mixed fishery with cod and redfish, so the high seas halibut quota shares for 2013-2015 are found by using the high seas quotas for halibut, cod, and other fish species. These high seas halibut quota shares can be seen in Table 15, and these shares together with the total high seas cost of harvesting all species can be used to find the total high seas costs of harvesting halibut for 2013-2015. The total high seas costs of harvesting halibut are also shown in Table 15 for 2013-2015, but these costs may reflect stochastic variation in fisheries-related conditions. To reduce the effect of random events, we use the average high seas costs of harvesting halibut for the three years, and this average is also shown in Table 15. From Table 9, we have information about the high seas halibut harvest for 2013-2015, and this is also reported in Table 15 together with the average high seas halibut harvest. Furthermore, from Table 12, we have information about the total halibut stock size for 2013-2015, and from this, we can calculate the average halibut stock size reported in Table 15. By using the total high seas cost of harvesting halibut, the total high seas halibut harvest, and the halibut stock size, measured by the averages, we can calculate the high seas cost parameter by using (8). This cost parameter is reported in Table 15, but due to the calculation method, the parameter value is highly uncertain, implying that sensitivity analyses become important. Thus, we will vary the high seas cost parameter with +/- 50%, and the upper and lower bound generated by this variation is also summarized in Table 15.

3.1.3. Coastal cost function.

A coastal industry cost function that fulfills the assumptions about the derivatives from the theoretical model is:

$$C_C(h_C, x) = c_C \frac{h_C{}^2}{x} \tag{9}$$

where c_C is a coastal cost parameter, h_C is the coastal industry halibut harvest, x is the halibut stock size, and $C_C(h_C, x)$ is the total coastal industry cost of harvesting halibut. As in section 3.1.2, we only have total coastal cost and harvest information for three years, so we must calculate the coastal cost parameter by using:

$$c_C = \frac{C_C(h_C, x)x}{h_C{}^2} \tag{10}$$

However, compared to the high seas cost parameter, an additional problem arises with the coastal cost parameter. For the coastal area, the total industry cost and harvest are decomposed into two categories represented by vessels above 6 meters (Table 10) and boats below 6 meters (Table 11). Thus, we must aggregate the total costs and harvest information for the two fleet segments, and the method used for doing this is summarized in Table 16.

Table 16: Coastal cost parameter.

From Table 10, we have the total coastal costs of harvesting all species for vessels above 6 meters for 2013-2015 while Table 11 contains similar information for the coastal boats below 6 meters, and this cost information has been inserted in Table 16. One approach is to calculate the total cost of harvesting halibut for each fleet segment by using halibut quota shares for vessels above and boats below 6 meters. However, from Table 4, only the total halibut quota is allocated on vessels above and boats below 6 meters, so this method cannot be used. Thus, we must aggregate the total coastal industry costs of harvesting all species for the two fleet segments for 2013-2015, and this is also done in Table 16. To calculate the total coastal costs of harvesting halibut, we use halibut quota shares as before and from Tables 10 and 11 both fleet segments, mainly harvested halibut in a mixed fishery with cod. Thus, based on Table 4, we can calculate the coastal halibut quota share for all vessels, and this share is also reported in Table 16 for 2013-2015. By using the coastal halibut quota shares, we can calculate the total coastal cost of harvesting halibut for the period between 2013 and 2015, but to reduce the implications of stochastic events, we take a simple average of these three observations that is reported in Table 16. From Tables 10 and 11, we have information on the halibut harvest for vessels above 6 meters and boats below 6 meters, and this information is inserted into Table 16 together with the aggregated total and average halibut harvest for both fleet segments. As in Table 15, we also use the halibut stock size for 2013-2015 to calculate an average halibut stock size, and by using the average total coastal cost of harvesting halibut, the average halibut harvest, and the average halibut stock size, we can calculate a coastal cost parameter by using (10). This coastal cost parameter is reported in Table 16, but for obvious reasons, this parameter estimate is highly uncertain, so we conduct sensitivity analyses by varying the coastal cost parameter by +/- 50 %. The upper and lower bounds for the cost parameter are also reported in Table 16.

3.1.4. High seas price.

From the theoretical model, the high seas halibut price is assumed to be constant and given as p_H , and from Statistics Greenland (2020) we can obtain information about the halibut price directly. However, in order to identify the high seas cost parameter and price consistently, we will use a similar procedure as in Table 15. This procedure is summarized in Table 17.

Table 17: High seas price.

From Table 9, we have information about the total high seas revenue of harvesting all species for 2013-2015, and now we can calculate the high seas revenue of harvesting halibut by using the high seas halibut quota shares from Table 15. This information is provided in Table 17 for 2013-2015, but to reduce the implications of random events, we take a simple average of these three observations. From Table 9, we have information about the total high seas halibut harvest for 2013-2015 and the average halibut harvest for these three years. Now, by using the average high seas revenue from harvesting halibut and the average halibut harvest, we can calculate a high seas halibut price that is reported in Table 17. However, this method generates a highly uncertain high seas halibut price, so we conduct a sensitivity analysis by varying the price by +/- 50 %. This generates an upper and lower bound that can be found in in Table 17.

3.1.5. Coastal price.

The constant coastal price is denoted p_C, and this price is found by combining the methods described in section 3.1.3. and 3.1.4. The calculations are summarized in Table 18.

Table 18: Coastal price.

From Tables 10 and 11, we have information about the total coastal revenue of harvesting all species for vessels above 6 meters and boats below 6 meters. The total coastal revenue for these two fleet segments can be aggregated, and the total coastal revenue for both fleet segments for 2013-2015 can be found in Table 18. By using the coastal halibut quota shares from Table 16, we can now calculate the total coastal revenue obtained by harvesting halibut for 2013-2015 and based on this an average coastal revenue for harvesting halibut can be found. From Table 16, we also have information about the average halibut harvest for both fleet segments, and by using this information together with the average coastal revenue, a coastal price on halibut can be calculated. This coastal price has been inserted in Table 18 together with the upper and lower bounds generated by varying the price of halibut by +/- 50 %.

3.1.6. Scaling factor for vessels from other fishing nations.

In the theoretical model, β denoted the scaling factor for the high seas harvests allocated to other fishing nations. Because the halibut harvest by other nations is determined through international fishing agreements that normally cover a long time period, β can be found by using the information about the total halibut quotas from Tables 3, 5 and 6. It should be noted that even though we have quota information for 2013-2016, we chose to exclude the observations for 2016 in order to secure consistency with the data period for price and cost information. The calculations of the scaling factor for other fishing nations are summarized in Table 19.

Table 19: Scaling factor for vessels from other fishing nations.

From Table 3, we have the total halibut quota allocated to high seas vessels from Greenland for 2013-2015. The halibut quota allocated to the EU is obtained from Table 5 while the halibut quota allocated to other fishing nations can be found in Table 6. To be consistent with the method used for the other parameters, we have calculated the average quota to Greenland, the EU, and other fishing nations in Table 19. Now the scaling factor for vessels from other fishing nations is easy to find, and this scaling factor is reported in Table 19. This scaling factor is reasonably certain, but to secure consistency with the other parameter values, we vary the scaling factor by +/- 50 % to generate an upper and lower bound which is reported in Table 19.

3.1.7. Land-based cost function.

Coastal vessels normally deliver all landings of halibut for land-based processing while high seas vessels are restricted by a land obligation that requires that 25 % of the halibut harvest shall be delivered for land-based processing. A land-based industry cost function that captures the landing obligation and fulfills the assumptions about the derivatives from the theoretical model is:

$$C_L(h_C, h_H) = c_L(h_C + 0.25h_H)^2 \tag{11}$$

where c_L is a land-based cost parameter and $C_L(h_C, h_H)$ is the total land-based cost of halibut at the west coast. With this cost function, we obtain the following marginal cost functions:

$$\frac{\partial C_L}{\partial h_C} = 2c_L(h_C + 0.25h_H) \tag{12}$$

$$\frac{\partial C_L}{\partial h_H} = 0.5c_L(h_C + 0.25h_H) \tag{13}$$

For calculating the land-based cost parameter, we only have information for three years for the high seas and coastal halibut harvest, so as for the other cost parameters, we must calculate c_L in a simple way. This is done by rewriting (11) as:

$$c_L = \frac{C_L(h_C, h_H)}{(h_C + 0.25h_H)^2} \tag{14}$$

Compared to the previous industry cost functions, three issues arise in relation to (14). First, we can only obtain an indirect measure of the total land-based costs. From Table 1, we have information about the total costs in the primary fishery industry while the total costs of the whole fishing sector are obtained from Table 2. We use the difference between these two cost numbers to obtain a measure of the total land-based costs. Second, the total land-based cost observations cover both the west and east coast and all fish species. Thus, we must allocate the total land-based costs to the west coast and, after this, to halibut. Third, since we consider the processing industry, it is not obvious that the costs should be allocated by using quota shares as for the primary fishery. However, for our purpose, it is important that the cost observations are as comparable as possible, and, therefore, we choose to use quota shares to allocate the land-based costs. The exact way these three issues have been addressed can be seen in Table 20.

Table 20: Land-based cost parameter.

In Table 20, we start by subtracting the total costs of the whole fishing sector from the total costs of the primary fishing industry. This generates the total land-based processing costs for 2013-2015. Next, from Statistics Greenland (2020), we can find the total quota for all fish species in each area and based on this the quota share of the west coast can be found. This share can be used to find the total land-based costs at the west coast. From this, we must find the total land-based processing costs of halibut, and here we choose to use high seas halibut quota shares calculated by using Tables 3 and 4. The total land-based costs of halibut at the west coast cover 2013-2015, and we use a simple average of these observations. From Tables 10 and 11, we have the total coastal halibut harvest, and by using the information from Table 9, we can find 25 % of the total high seas halibut harvest. These two harvest numbers can be aggregated, and an average harvest can be found. Now we can calculate the land-based cost parameter by using (14), and this parameter has been inserted in Table 20. However, this method generates a highly uncertain land-based cost parameter estimate, so we construct an upper and lower bound by varying the cost parameter by +/- 50 %, and the two bounds can also be found in Table 20.

3.1.8. Land-based price.

Now we want to find the land-based price of halibut (the price of halibut delivered from land-based processing factories), and here we combine the methods used in sections 3.1.4 and 3.1.7. The exact procedure is summarized in Table 21.

Table 21: Land-based price.

By subtracting the total revenue for the whole fishing industry from Table 2 from the total revenue for the primary fishing sector from Table 1, we obtain the total land-based revenue. Now we use the quota shares from Table 20 to find the total land-based revenue for the west coast. Then we use the halibut quota shares from Table 20 to find the total land-based revenue of halibut from the west coast. We can obtain information about this land-based revenue for 2013-2015, and we take a simple average of these observations. From Table 8, we have information about the amount of halibut delivered from land-based processing factories for 2013-2015, and we can also take a simple average of these observations. Now we can calculate the land-based price by sharing the land-based revenue with the quantity, and this price can be found in Table 21. However, this calculation method is very uncertain, so we construct upper and lower bounds by varying the land-based price by +/- 50 %, and these bounds can also be found in Table 21.

3.1.9. Processing loss in land-based factories.

Now we want to determine α that measures the processing loss in land-based factories. This loss is measured by the share of the halibut harvest left after land-based processing has taken place. The calculations of this share are summarized in Table 22.

Table 22: Processing loss in land-based factories.

From Table 7, we have the halibut quantity delivered for land-based processing for 2013-2015 while Table 8 contains the halibut quantity delivered by land-based processing factories. This information has been inserted in Table 22, and average values have been calculated. Now we can identify the share of the halibut that is left after land-based processing has taken place by sharing the quantity delivered from land-based processing with the quantity that enters. This share has been inserted in Table 22 where we also report an upper and a lower bound for the share by varying this by +/- 50 %. It should be noted that because the upper bound for the share becomes larger than one, we have set this equal to one, implying that nothing is lost during land-based processing.

3.1.10. Equity weight.

In the theoretical model, λ represents an equity weight, and we will assume that $\lambda \geq 1$, implying that the coastal profit has a higher value than the high seas profit. However, we have no information about the equity weight, so we will vary λ in order to investigate how our results are affected by the weight imposed on the coastal profit.

3.2. Two separate fish stocks.

3.2.1. High seas and coastal natural growth functions and migration function.

For the high seas fish stock, a logistic growth function fulfills the assumptions about the derivatives of the growth function. The logistic function for the high seas fish stock is given by:

$$G_H(x_H) = r_H x_H (1 - \frac{x_H}{K_H}) \tag{15}$$

where r_H is the high seas intrinsic growth rate and K_H is the high seas carrying capacity. For the coastal fish stock, we also assume a logistic function is given by:

$$G_C(x_C) = r_C x_C (1 - \frac{x_C}{K_C}) \tag{16}$$

where r_C is the coastal intrinsic growth rate and K_C is the coastal carrying capacity. A net migration function for halibut that fulfills the assumptions about the derivatives from the theoretical model is:

$$M(x_H, x_C) = m \frac{x_H}{x_C} \tag{17}$$

where m is a net migration parameter for halibut.

To estimate the high seas and coastal growth functions and the migration function for halibut, we may (as in section 3.1.1) use two strategies. First, we can use the fact that the observations for the coastal natural growth from Table 13 include the net migration function for halibut from the high seas area to the coastal area. Thus, it becomes possible to estimate:

$$G_C(x_C, x_H) = r_C x_C - \frac{r_C x_C^{\ 2}}{K_C} + m \frac{x_H}{x_C} \tag{18}$$

where $G_C(x_C, x_H)$ are the observations for the coastal natural growth from Table 13. By using the estimated parameter for m and the time series for x_H and x_C from Table 13, we can now calculate a time series for the net migration of halibut. Since the net migration of halibut must be identical for the high seas and coastal areas, we can now estimate:

$$G_H(x_C, x_H) + m \frac{x_H}{x_C} = r_H x_H - \frac{r_H x_H^{\ 2}}{K_H} \tag{19}$$

where $G_H(x_C, x_H)$ is the time series for the high seas natural growth from Table 13, and $m \frac{x_H}{x_C}$ is a calculated time series for the net migration of halibut.

Second, we can assume a steady-state equilibrium and estimate the following steady-state relation for the coastal fish stock:

$$h_C = r_C x_C - \frac{r_C x_C^{\ 2}}{K_C} + m\frac{x_H}{x_C} \qquad (20)$$

As before, we can now calculate a time series for the net migration of halibut by using m and the time series for x_H and x_C from Table 13. By assuming a steady-state equilibrium for the high seas fish stock, we can then estimate:

$$h_H + \beta h_H + m\frac{x_H}{x_C} = r_H x_H - \frac{r_H x_H^{\ 2}}{K_H} \qquad (21)$$

where $m\frac{x_H}{x_C}$ is the calculated time series for the net migration of halibut.

(20) and (21) can be estimated by using the time series for the high seas and coastal stock size and harvest. However, as in section 3.1.1, an important problem with this method is that we assume that both the high seas and coastal stock sizes are in a steady-state equilibrium. A plot of the high seas and coastal stock sizes from Table 13 shows that this assumption may be potentially critical for both fish stocks because these do not necessarily fluctuate stochastically around mean values. However, to secure consistency with the way that we have estimated the growth function in section 3.1.1, we assume that both stock sizes are in a steady-state equilibrium, so we have chosen to estimate (20) and (21).

For estimation purposes, we transform (20) into:

$$h_C = a_C x_C - b_C x_C^{\ 2} + m\frac{x_H}{x_C} \qquad (22)$$

where a_C , b_C and m are estimated coastal parameters. Now, by comparing (20) and (22), we get that:

$$a_C = r_C \qquad (23)$$

$$K_C = \frac{r_C}{b_C} \qquad (24)$$

For estimation purposes, we also transform (21) into:

$$y = a_H x_H - b_H x_H^{\ 2} \qquad (25)$$

where y is the sum of the high seas harvest and the calculated net migration of halibut while a_H and b_H are estimated high seas parameters. By comparing (20) and (25), we get that:

$$a_H = r_H \qquad (26)$$

$$K_H = \frac{r_H}{b_H} \qquad (27)$$

The results of estimating (22) with OLS and using (23) and (24) to calculate the relevant parameter values are shown in Table 23.

Table 23: Coastal natural growth and migration function.

From Table 23, we see that r_C is positive and significant while b_C is insignificant. *m* is positive but insignificant, and the positive value of *m* implies a net migration from the high seas area to the coastal fish area. By using (24), we can calculate K_C by using r_C and b_C, and the coastal carrying capacity is also reported in Table 23. R^2 is reasonably high, but the Durbin-Watson test generates a value of 0.234. With a critical level of 0.727, we have a potential problem with positive serial correlation, but we follow the main tradition within fisheries economics and make no attempt to correct for serial correlation. As for the common fish stock, we conduct sensitivity analyses by varying r_C and *m* by +/- 50 %, and the upper and lower bounds generated by this variation are shown in Table 23. We also vary b_C by +/- 50 % and assume that all variation in b_C is due to variation in K_C. Thus, we can use (24) to generate upper and lower bounds for K_C that are reported in Table 23.

The results of estimating (25) with OLS and using (26) and (27) to calculate r_H and K_H are shown in Table 24.

Table 24: High seas natural growth function.

From Table 24, we see that r_H is positive and significant while b_H is insignificant. By using (27), we can calculate K_H from r_H and b_H. R^2 is reasonably high, but with a Durbin-Watson test value of 0.135 and a critical level of 0.810, we have a potential problem with positive serial correlation. However, as mentioned above, it is common not to try to correct for serial correlation in fisheries economics. To discuss the implications of statistical uncertainty, we vary the estimated parameter of r_H by +/- 50 % to yield an upper and lower bound that are reported in Table 24. We also vary b_H by +/- 50 % and assume that all variation in b_H is due to variation in K_H. This implies that we can use (27) to find an upper and a lower bound for K_H that are reported in Table 24.

3.2.2. High seas cost function.

A high seas industry cost function that fulfills the assumptions about the derivatives from the theoretical model is:

$$C_H(h_H, x_H) = c_H \frac{{h_H}^2}{x_H} \tag{28}$$

where c_H is a high seas cost parameter and x_H is the high seas halibut stock size. By reorganizing (28) we get that:

$$c_H = \frac{C_H(h_H, x_H)x_H}{{h_H}^2} \tag{29}$$

By comparing (8) and (29), we see that the only difference is that now we will use the high seas halibut stock size from Table 13 instead of the common halibut stock size from Table 12. Thus, the calculations are exactly the same as in Table 15 apart from the fact that the halibut stock size differs, and the procedure is summarized in Table 25.

Table 25: High seas cost parameter.

In Table 25, we have inserted the high seas halibut stock size between 2013 and 2015 and used these observations to calculate an average high seas stock size. By using the average high seas stock size, we can calculate the high seas costs parameter with the procedure from (29), and compared to the model with a common fish stock, the high seas cost parameter is lower because the high seas stock size is lower. However, this way of quantifying a high seas cost parameter implies huge uncertainty, so we will perform sensitivity analyses by varying the high seas cost parameter by +/- 50 %. The upper and lower bounds generated by this variation are summarized in Table 25.

3.2.3. Coastal cost function.

A coastal industry cost function that fulfills the assumptions about the derivatives from the theoretical model is:

$$C_C(h_C, x_C) = c_C \frac{h_C^{\ 2}}{x_C} \tag{30}$$

where c_C is a coastal cost parameter and x_C is the coastal halibut stock size. (30) can be rewritten as:

$$c_C = \frac{C_C(h_C, x_C)x_C}{h_C^{\ 2}} \tag{31}$$

Thus, the only difference compared to the model with a common fish stock is that the coastal halibut fish stock from Table 13 will be used instead of the common halibut fish stock in Table 12. The coastal fish stock has been included in Table 26.

Table 26: Coastal cost parameter.

Naturally enough, the coastal cost parameter in Table 26 decreases compared to a common fish stock because the stock size is lower. We have inserted the coastal cost parameter in Table 26 together with the upper and lower bounds generated by varying the cost parameter by +/- 50 %.

3.2.4. High seas price.

The high seas halibut price is unchanged compared to the model with a common fish stock. Thus, the high seas price can be found by performing the same calculations as in Table 17, and the price is summarized in Table 17 together with the upper and lower bounds.

3.2.5. Coastal price.

The coastal price has already been found in section 3.1.5, and the calculations are summarized in Table 18. Furthermore, the coastal price together with the upper and lower bound can be found in Table 18.

3.2.6. Scaling factor for vessels from other fishing nations.

The scaling factor for vessels from other fishing nations is the same as in the model with a common fish stock. Thus, the calculations are summarized in Table 19, and the calculated scaling factor is summarized in Table 19 together with the upper and lower bounds.

3.2.7. Land-based cost function.

The land-based cost function is the same as with a common fish stock, implying that the calculations can be found in Table 20. The land-based costs parameter and the upper and lower bound can be seen in Table 20.

3.2.8. Land-based price.

The land-based price is also unchanged compared to the model with a common fish stock. Thus, Table 21 summarizes the method used for calculation of the land-based price, and the price together with the upper and lower bound are summarized in Table 21.

3.2.9. Processing loss in land-based factories.

The processing loss in land-based factories is the same as with a common stock. Thus, the calculations can be found in Table 22, and the estimated value as well as the upper and lower bounds can be found in Table 22.

3.2.10. Equity weight.

As in the model with a common fish stock, we vary the equity weight to investigate how our results are affected by the weight imposed on the coastal profit.

References.

Jørgensen, O.A. (2013). Distribution of Small Greenland Halibut in Baffin Bay. Technical Report no. 89, Greenland Institute of Natural Resources.

Ogmundsson, H. (2019). Baggrundsnotat. Relevante Data om Økonomi og Beskæftigelse i Fiskerierhvervet, November 2019, Government of Greenland.

Ogmundsson, H. and Haraldson, G. (2017). Redegørelse af Ressourcerenten i det Grønlandske Fiskeri og Forslag til Nye Ressourcerenteafgiftsmodeller, Department for Finance and Taxes, Government of Greenland.

Statistics Greenland (2020). Fisheries and Harvest. Nuuk.

Treble, M.A. and Nogueira, A. (2018). Assessment of the Greenland Halibut Stock Components in NAFO Subarea 0 + Division 1.A (Offshore) and Divisions 1B – 1F. Scientific Council Meeting, June 2018, Northwest Atlantic Fisheries Organization.

Table 1: Economic indicator for the primary fishing industry, 2010-2015.

Year	**Revenue** (mill. DKK)	**Accounting cost** (mill. DKK)	**Accounting profit** (mill DKK)
2010	2,013	1,801	212
2011	1,199	923	276
2012	2,123	1,847	276
2013	2,413	2,044	369
2014	2,314	1,836	478
2015	2,111	1,712	399

Source: Personal communication with Hilmar Ogmundsson based on Ogmundsson (2019).

Table 2: Economic indicators for the whole fishing industry, 2010-2015.

Year	**Revenue** (mill. DKK)	**Accounting cost** (mill. DKK)	**Accounting profit** (mill. DKK)
2010	3,734	3,483	251
2011	4,233	3,779	454
2012	4,301	3,760	541
2013	4,281	3,943	338
2014	4,590	4,239	351
2015	5,707	5,030	677

Source: Ogmundsson and Haraldson (2017).

Table 3: High sea quotas at the west and east coast, 2013-2016.

Area	**Fish species**	**2013**	**2014**	**2015**	**2016**
West coast	**Shrimp** (tons)	49,802	47,262	41,075	47,425
	Halibut (tons)	8,075	8,075	9,725	9,725
	Cod (tons)	5,000	5,000	7,000	5,000
	Other species (tons)	17,120	27,120	32,620	32,620
East coast	**Shrimp** (tons)	4,900	800	800	800
	Halibut (tons)	3,685	3,685	3,803	1,797
	Other species (tons)	160,696	157,025	174,130	146,130
West and east coast	**Cod** (tons)	3,550	6,245	6,445	11,875

Source: Statistics Greenland (2020).

Table 4: Coastal quotas at the west coast, 2013-2016.

Fish species	Fleet segment	2013	2014	2015	2016
Shrimp (tons)		36,061	35,654	30,986	35,776
Halibut (tons)		24,700	26,394	28,200	28,500
	Vessels above 6 meters	11,577	11,577	12,270	12,270
	Boats below 6 meters	13,123	14,817	15,930	15,930
Cod (tons)		15,000	18,500	27,500	26,000
Other species (tons)		2,780	2,800	4,300	3,900

Source: Statistics Greenland (2020).

Table 5: High seas quota of vessels from the EU at the west and east coast, 2013-2016.

Area	**Fish species**	**2013**	**2014**	**2015**	**2016**
West coast	**Shrimp** (tons)	3,400	3,400	3,400	2,600
	Halibut (tons)	2,500	2,500	2,500	2,500
	Other species (tons)	300	100	100	100
East coast	**Shrimp** (tons)	7,500	7,500	7,500	5,100
	Halibut (tons)	4,315	4,315	4,315	4,315
	Other species (tons)	300	300	300	100
West and east coast	**Cod** (tons)	2,200	2,200	2,200	2,200
	Other species (tons)	65,250	65,250	65,250	24,000

Source: Statistics Greenland (2020).

Table 6: High seas halibut quota of vessels from other countries at the west coast, 2013-2016.

Country	**2013**	**2014**	**2015**	**2016**
Russia (tons)	1,775	1,775	1,775	1,775
Faroe Island (tons)	100	100	100	100
Norway (tons)	1,475	1,475	1,475	900

Source: Statistics Greenland (2020).

Table 7: Quantity of fish delivered for land-based processing at the west and east coast, 2013-2015.

Fish species	**2013**	**2014**	**2015**
Shrimp (tons)	50,167	45,551	36,880
Halibut (tons)	25,291	30,095	28,191
Cod (tons)	14,587	21,063	33,933
Stone chunks (tons)	14,791	8,127	7,162
Other species (tons)	4,003	4,385	3,766

Source: Ogmundsson and Haraldson (2017)).

Table 8: Quantity of fish produced by land-based processing factories, 2013-2015.

Fish species	**2013**	**2014**	**2015**
Shrimp (tons)	30,215	24,766	20,123
Halibut (tons)	20,120	22,233	21,256
Cod (tons)	10,113	15,215	20,122

Source: Personal communication with Hilmar Ogmundsson based on Ogmundsson (2019).

Table 9: Economic indicators for high sea vessels targeting halibut at the west coast, 2013-2015.

Indicator	**Indicator**	**2013**	**2014**	**2015**
Revenue (mill. DKK)		435.4	543.7	614.4
Costs (mill. DKK) (with taxes and depreciation)		297.3	369.5	433.3
Taxes and depreciation (mill. DKK)	**Halibut tax**	15.4	19.8	27.1
	Mackerel tax		4.1	3.5
	User payment	1.6	1.9	2.0
	Depreciation	26.2	36.5	49.9
Costs (mill. DKK) (without taxes and depreciation)		254.1	307.2	350.8
Number of vessels		4	4	4
Harvest (tons)	**Halibut**	9,860	11,266	12,072
	Cod	9,078	8,491	9,630
	Redfish	5,700	4,230	3,776
	Chew	821	393	396
	Haddock	1,348	1,023	878
	Pelagic species	368	7,123	6,640
Quota utilization (%)	**Halibut**	97	89	72
	Cod	82	84	84

Source: Ogmundsson and Haraldson (2017).

Table 10: Economic indicators for coastal vessels above 6 meters targeting halibut at the west coast, 2013-2015.

Indicator	**Indicator**	**2013**	**2014**	**2015**
Revenue (mill. DKK)		117.3.	124.7	64.2
Costs (mill. DKK) (with depreciation)		72.9	85.5	34.9
Depreciation (mill. DKK)		8.9	10.5	7
Costs (mill. DKK) (without depreciation)		63	75	27.9
Number of vessels		77	79	32
Harvest (tons)	**Halibut**	10,350	11,203	8,907
	Cod	4,767	6,060	8,350
	Other species	1,894	1,662	1,684
Quota utilization (%)	**Halibut**	97	95	98

Source: Ogmundsson and Haraldson (2017).

Table 11: Economic indicators for coastal boats below 6 meters targeting halibut at the west coast, 2013-2015

Indicator	**Indicator**	**2013**	**2014**	**2015**
Revenue (mill. DKK)		264.3	284.3	374.5
Costs (mill. DKK) (with depreciation)		81.8	88.2	123.1
Depreciation (mill. DKK)		7.2	10.8	12.6
Costs (mill. DKK) (without depreciation)		74.6	77.4	110.5
Number of vessels		1,432	1,541	1588
Harvest (tons)	**Halibut**	13,069	15,300	16,009
	Cod	5,136	9,424	12,609
Quota utilization (%)	**Halibut**	99%	98%	99%

Source: Ogmundsson and Haraldson (2017).

Table 12: Stock size, harvest and growth of halibut at the west coast, 1997-2017.

Year	**Stock size** (tons)	**Harvest by all nations** (tons)	**Natural growth** (tons)	**Quota utilization** (%)
1997	63,453	9,101		
1998	71,456	8,652	16,695	
1999	68,715	9,671	6,930	
2000	65,715	10,566	7,566	
2001	74,517	13,780	22,562	
2002	74,778	14,877	15,138	
2003	72,712	18,696	16,630	
2004	75,716	19,052	22,056	
2005	80,209	19,716	24,209	
2006	78,715	23,704	22,270	
2007	73,134	23,388	17,807	
2008	89,718	22,183	38,757	
2009	73,123	24,672	8,077	
2010	75,718	27,049	29,644	
2011	92,213	26,553	43,048	
2012	64,715	27,513	15	
2013	64,174	28,429	27,888	76
2014	62,671	31,433	29,930	85
2015	76,937	31,861	40,127	86
2016	75,841	31,145	30,049	84
2017	77,895	34,652	36,719	

Source: Personal communication with Margaret A. Treble based on NAFO (2019) and own calculations.

Table 13: High seas and coastal stock size, harvest, and growth of halibut at the west coast, 1997-2017.

Year	**High seas** (share)		**High seas**			**Coastal**		
	Stock size	**Harvest**	**Stock size** (tons)	**Harvest** (tons)	**Growth** (tons)	**Stock size** (tons)	**Harvest** (tons)	**Growth** (tons)
1997	0,61	0.7066	38,706	6,431		24,747	2,670	
1998	0,49	0.7066	35,013	6,142	2,449	36,443	2,550	14,246
1999	0,73	0.7066	50,162	6,833	21,982	18,553	2,838	-15,052
2000	0,58	0.7066	38,115	7,466	-4,582	27,600	3,100	12,148
2001	0,59	0.7066	43,965	9,722	15,573	30,552	4,038	6,989
2002	0,60	0.7066	44,867	10,512	11,413	29,911	4,365	3,725
2003	0,61	0.7066	44,345	13,210	12,698	28,358	5,486	3,932
2004	0,58	0.7066	43,915	13,462	13,023	31,801	5,590	9,033
2005	0,66	0.7066	52,938	13, 931	22,953	27,271	5,785	1,256
2006	0,78	0.7066	61,398	16,781	25,251	17,317	6,963	-2,981
2007	0,73	0.7066	53,388	16,525	8,515	19,746	6,863	9,292
2008	0,84	0.7066	75,363	15,674	37,649	14,355	6,509	1,118
2009	0,80	0.7066	58,498	17,433	567	14,625	7,239	7,509
2010	0,76	0.7066	57,546	19,112	18,159	18,172	7,937	11,485
2011	0,75	0.7066	69,160	18,762	30,376	23,053	7,791	12,672
2012	0.62	0.7066	40,123	19,440	-9, 597	24,592	8,073	9,612
2013	0.62	0.7066	39,788	20,087	19,752	24,386	8,342	8,136
2014	0.62	0.7066	38,856	22,421	21,278	23,815	9,012	8,652
2015	0.62	0.7066	47,701	22,512	31,357	29,236	9,349	14,770
2016	0.62	0.7066	47,021	22,006	21,327	28,820	9,139	8,7223
2017	0.62	0.7066	48,295	24,491	25,765	29,600	10,170	10,951

Source: Personal communication with Ole A. Jorgensen based on Jorgensen (2013), personal communication with Magaret A, Treble based on NAFO (2019) and own calculations.

Table 14: Natural growth function.

Parameter	**Estimate**	**Standard derivation**	**t-value**	**Lower bound**	**Upper bound**
Intrinsic growth rate (r)	0.3485	0.2289	1.52228	0.17425	0.52275
Parameter (b)	0.000000726	0.000003015	0.2411		
Carrying capacity (K)	480,027			295,785	887,356
$\mathbf{R^2}$	0.88				
Durbin-Watson (DW)	0.178				

Table 15: High seas cost parameter.

Indicator	2013	2014	2015	Average
Industry costs (mill. DKK) (all species)	254.1	307.2	354.8	
Halibut quota share	0.2674	0.2009	0.2259	
Industry costs (mill. DKK) (halibut)	67.9536	61.7151	80.1587	69.9425
Harvest (tons)	9,860	11,266	12,072	11,070
Stock size (tons)	64,174	62,671	76,937	67,909
Cost parameter (mill. DKK/tons)				0.03876
Lower bound (mill. DKK/tons)				0.019384
Upper bound (mill. DKK/tons)				0.058151

Table 16: Coastal cost parameter.

Indicator	**2013**	**2014**	**2015**	**Average**
Costs (mill. DKK) (vessels above 6 meters) (all species)	63	75	27.9	
Costs (mill. DKK) (boats below 6 meters) (all species)	74.6	77.4	110.5	
Costs (mill. DKK) (all species)	137.8	152.4	138.4	
Halibut quota share	0.62217	0.58792	0.50628	
Cost (mill. DKK) (halibut)	85.6101	89.5987	70.0679	81.7595
Harvest (tons) (vessels above 6 meters)	10,350	11,203	8,907	
Harvest (tons) (boats below 6 meters)	13,069	15,300	16,009	
Harvest (tons)	23,417	26,503	24,917	24,917
Stock size (tons)	64,174	62,671	76,937	67,909
Cost parameter (mill. DKK/tons)				0.00892
Lower bound (mill. DKK/tons)				0.00446
Upper bound (mill. DKK/tons)				0.01339

Table 17: High seas price.

Indicator	**2013**	**2014**	**2015**	**Average**
Revenue (mill. DKK) (all species)	435.4	543.7	614.4	
Halibut quota share	0.2674	0.2009	0.2259	
Revenue (mill. DKK) (halibut)	116.44	109.23	121.09	115.58
Harvest (tons)	9,860	11,266	12,072	11,070
Price (mill. DKK/tons)				0.01097
Lower bound (mill. DKK/tons)				0.00549
Upper bound (mill. DKK/tons)				0,01646

Table 18: Coastal price.

Indicator	2013	2014	2015	Average
Revenue (mill. DKK) (vessels above 6 meters) (all species)	117.3	124.7	64.2	
Revenue (mill. DKK) (boats below 6 meters) (all species)	264.3	284.3	374.5	
Revenue (mill. DKK) (all species)	381.6	409	438,7	
Halibut quota share	0.62217	0.58792	0.50628	
Revenue (mill. DKK) (halibut)	237.42	240,46	222.11	233,33
Harvest (tons) (vessels above 6 meters)	10,350	11,203	8,907	
Harvest (tons) (boats below 6 meters)	13,069	15,300	16,009	
Harvest (tons)	23,417	26,503	24,917	24,917
Price (mill. DKK/tons)				0.00935
Lower bound (mill. DKK/tons)				0.00468
Upper bound (mill. DKK/tons)				0.01403

Table 19: Scaling factor for vessels from other fishing nations.

Indicator	**2013**	**2014**	**2015**	**Average**
Halibut quota (tons) (Greenland)	8,075	8,075	9,725	8,625
Halibut quota (tons) (EU)	2,500	2,500	2,500	2,500
Halibut quota (tons) (other nations)	3,350	3,350	3,350	3,335
Scaling factor				0.677
Lower bound				0.3385
Upper bound				1.0155

Table 20: Land-based cost parameter.

Indicator	2013	2014	2015	Average
Costs (mill. DKK) (fishing industry) (both areas) (all species)	3.943	4.239	5.030	
Costs (mill. DKK) (primary fishery) (both areas) (all species)	2,044	1.836	1.712	
Costs (mill. DKK) (land-based processing) (both areas) (all species)	1,899	2,402	3,310	
Quota share (west coast)	0.321	0.351	0.336	
Cost (mill DKK) (land-based processing) (west coast) (all species)	609	844	1108	
Quota share **(halibut)**	0.2674	0.2009	0.2259	
Cost (mill. DKK) (land-based processing) (west coast) (halibut)	162.86	169.56	250.33	194.15
Coastal harvest (tons)	23,417	26,503	24,917	
25% of high seas harvest (tons)	2,468	2,817	3,019	
Total harvest (tons) (land-based processing)	25.687	29.320	27.935	27,714
Cost parameter (mill. DKK/tons)				$2.53*10^{-7}$
Lower bound (mill. DKK/tons)				$1.26*10^{-7}$
Upper bound (mill. DKK/tons)				$3.97*10^{-7}$

Table 21: Land-based price.

Indicator	2013	2014	2015	Average
Revenue (mill. DKK) (fishing industry) (both areas) (all species)	4.281	4,590	5,707	
Revenue (mill. DKK) (primary fishery) (both areas) (all species)	2,413	2.314	2.111	
Revenue (mill. DKK) (land-based processing) (both areas) (all species)	1,868	2,276	3,596	
Quota share (west coast)	0.321	0.351	0.336	
Revenue (mill. DKK) (land-based processing) (west coast) (all species)	599.17	799.51	1208.65	
Quota share (halibut)	0.2674	0.2009	0.2259	
Revenue (mill. DKK) (land-based processing) (west coast) (halibut)	160.24	160.62	272.07	197.97
Production (tons)	20,120	22,233	21,256	21,229
Price (mill. DKK/tons)				0.00714
Lower bound (mill. DKK/tons)				0.00357
Upper bound (mill. DKK/tons)				0.01072

Table 22: Processing loss in land-based factories.

Indicator	2013	2014	2015	Average
Halibut (tons) (for land-based processing)	25,291	30,095	28,191	26,192
Halibut (tons) (from land-based processing**)**	20,120	22,233	21,256	21,229
Processing loss				0.92
Lower bound				0.46
Upper bound				1

Table 23: Coastal natural growth and migration function.

Parameter	Estimate	Standard derivation	t-value	Lower bound	Upper bound
Intrinsic growth rate (r_C)	0.579	0.242	2.839	0.2895	0.8685
Parameter (b_C)	0.00001305	0.000007276	1.794		
Carrying capacity (K_C)	44,367			29,578	88,735
Migration parameter (m)	237.009	643.789	0.3681	118.5045	355.5125
R^2	0.82				
Durbin-Watson (DW)	0.234				

Table 24: High seas natural growth function.

Parameter	Estimate	Standard derivation	t-value	Lower bound	Upper bound
Intrinsic growth rate (r_H)	0.483	0.114	4.225	0.2415	0.7242
Parameter (b_H)	0.00000307	0.0000028	1.477		
Carrying capacity (K_H)	157,339			104,885	314,057
R^2	0.84				
Durbin-Watson (DW)	0.1350				

Table 25: High seas cost parameter.

Indicator	**2013**	**2014**	**2015**	**Average**
Costs (mill. DKK) (all species)	254.1	307.2	354.8	
Halibut quota share	0.2674	0.2009	0.2259	
Cost (mill. DKK) (halibut)	67.9536	61.7151	80.1587	69.9425
Harvest (tons)	9,860	11,266	12,072	11,070
Stock size (tons)	39,788	38,856	47,701	42,102
Cost parameter (mill. DKK/tons)				0.024036
Lower bound (mill. DKK/tons)				0.012018
Upper bound (mill. DKK/tons)				0.036054

Table 26: Coastal cost parameter.

Indicator	**2013**	**2014**	**2015**	**Average**
Costs (mill. DKK) (vessels above 6 meters) (all species)	63	75	27.9	
Costs (mill. DKK) (boats below 6 meters) (all species)	74.6	77.4	110.5	
Costs (mill. DKK) (all species)	137.8	152.4	138.4	
Halibut quota share	0.62217	0.58792	0.50628	
Cost (mill. DKK) (halibut)	85.6101	89.5987	70.0679	81.7595
Harvest (tons) (vessels above 6 meters)	10,350	11,203	8,907	
Harvest (tons) (boats below 6 meters)	13,069	15,300	16,009	
Harvest (tons)	23,417	26,503	24,917	24,917
Stock size (tons)	24,386	23,815	29,236	25,812
Cost parameter (mill. DKK/tons)				0.00339
Lower bound (mill. DKK/tons)				0.0017
Upper bound (mill. DKK/tons)				0.00509