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Science Response 2022/002

# DEVELOPMENT OF A PRECAUTIONARY APPROACH FOR THE GULF OF ST. LAWRENCE (4RST) GREENLAND HALIBUT STOCK

## Context

Since 2006, Canada has made national and international commitments to apply the precautionary approach (PA) in fisheries decision-making (DFO 2006). In recent years, Canada has taken several initiatives to define and establish benchmarks under the precautionary approach in the context of fisheries and incorporate them into fisheries management. Following recommendations made by the Commissioner of the Environment and Sustainable Development (CESD 2016), Fisheries and Oceans Canada (DFO) committed to developing and implementing a precautionary approach for the sustainable management of Greenland halibut (*Reinhardtius hippoglossoides*) in the Gulf of St. Lawrence (GSL, Northwest Atlantic Fisheries Organization [NAFO] Divisions 4RST).

Greenland halibut in the GSL is a stock for which a precautionary approach is under development. A stock status indicator and limit reference point have been established since February 2017 (DFO 2018). A working group, comprised of representatives from DFO (Science and Fisheries Management), the industry, the provincial governments of Quebec and Newfoundland and Labrador, and Aboriginal groups, was created in the fall of 2018 to develop a precautionary approach proposal. Objectives relating to the management of this stock, a target reference and upper stock reference points have been agreed on by the working group in 2020 (DFO 2021). The working group also considered the development of decision rules (hereinafter referred to as harvest control rules; HCR) and developed three HCR proposals. The Resource Management, Aquaculture and Aboriginal Affairs Directorate (hereafter referred to as Fisheries Management) has requested a Science Advice from the Regional Science Branch to determine the compliance of the proposed HCR according to the principles of the precautionary approach and to compare their advantages and disadvantages.

This Science Response stems from the Regional Science Response process of November 15, 2021 on the Development of the Gulf of St. Lawrence Greenland Halibut Precautionary Approach (4RST).

## Background

### The Precautionary Approach for Managing Fish Stocks in Canada

The fisheries decision framework incorporating the PA (Precautionary Approach Policy, DFO 2009) requires the definition of a stock status indicator, limit reference (LRP) and upper stock reference points (USR) delineating critical, cautious and healthy zones, a reference exploitation rate and HCR. The HCR determine the maximum allowable removals based on the stock status. The reference exploitation rate is normally expressed as a fishing mortality rate ($F$) or as a harvest rate.

According to the PA Policy, when the condition of the stock is in the healthy zone, the exploitation rate must not exceed the pre-established reference exploitation level. In the cautious zone, management measures should encourage stock recovery to the healthy zone and the exploitation rate should gradually decrease as the stock moves closer to the Critical Zone. In the cautious zone, there should be a relationship between exploitation rate and stock status, although the exact form of this relationship is not specified in the Policy. In the critical zone, conservation of the stock is the top priority and there should be no tolerance for a preventable decline. Exploitation rates must be kept to the lowest level possible. In addition, the revised *Fisheries Act* (2019) requires implementing measures to keep the stock above the LRP. These measures should also prevent further decline in stock status and should be implemented before this point is reached, and should have the objective of avoiding serious harm to the stock (DFO 2021a).

### Objectives of the developed PA

Conservation objectives for the commercial fishery were developed during the working group workshops to guide the development of the PA. These objectives are structured according to their time horizon and are described in Table 1. However, these objectives cannot be evaluated quantitatively since no short- and long-term projection of a population dynamics model or a management strategy evaluation exercise are currently available for this stock. The evaluation of these objectives will be carried out by monitoring Greenland halibut > 40 cm biomass indicator in the short, medium and long term.

*Table 1: Conservation objectives for commercial fisheries developed by the GSL Greenland halibut working group.*

| Timeline | Conservation objectives for the commercial fishery |
|---|---|
| Short term (0 to 5 years) | Stop the decline in spawning stock biomass (> 40 cm) to avoid reaching the LRP and initiate an increase in spawning stock biomass. |
| Medium term (5 to 10 years) | Promote an increase in spawning stock biomass (> 40 cm) to 80% of USR (30 192 t). |
| Long term (10 to 15 years) | Promote the return and maintenance of the spawning biomass of Greenland halibut in the healthy zone. |

Management objectives were also developed by the working group and are described in Table 2. Management strategies have been considered to limit variations in total allowable catch (TAC; management objective 1), to reduce unaccounted mortality in the Greenland halibut fishery as well as mortality in other fisheries (management objective 2). Socio-economic considerations (Management Objective 3) will not be addressed in this Science Response.

*Table 2: Management objectives developed by the GSL Greenland Halibut Stock Working Group and possible strategies to achieve them*

| Objective | Possible or ongoing management strategy |
|---|---|
| 1- Limit inter-annual variation in TAC while considering removals | - Stepped harvest control rules;<br>- Use of a smoothed stock status indicator;<br>- 2 year fixed TAC |
| 2- Reduce mortality in northern shrimp, redfish and Greenland halibut fisheries (better monitoring) | - Better documenting the different sources of fishing mortality (more specifically unaccounted mortalities);<br>- Optimizing fishing trip planning, promoting good behaviour (good fishing practice, compliant immersion times, unaccounted mortality, etc.);<br>- At-Sea Observer Program (coverage rates met);<br>- Monitoring and application of bycatch and small fish protocols<br>- Review of fishing season to avoid bad behaviour;<br>- More frequent removal of nets for better quality. |
| 3- Consider socio-economic considerations when establishing the TAC | - Decision criteria that incorporate socio-economic considerations and the establishment of a threshold for continuation of activities taking into account that some fishermen are more dependent on the Greenland halibut fishery than others. |

# Analysis and Response

### Indicator and reference points

The indicator selected for monitoring the stock status is the biomass of fish > 40 cm estimated from the northern GSL survey (nGSL). This survey covers almost the entire range of the stock and this indicator represents a proxy of the relative spawning stock biomass (DFO 2018), as the Greenland halibut catchability in this survey is not known.

The selected LRP is the geometric mean of the indicator over the 1990-1994 period, which corresponds to the period when the population was at its lowest level and from which a recovery of the stock was observed. This LRP is estimated at 10,000 metric tonnes (t) (Figure 1).

The USR was first proposed for this stock in 2018. This USR was based on observed stable biomass during a productive period of this stock from 2004-2012 (Figure 1). The high productivity of the stock during this period is largely due to the excellent recruitment produced in the late 1990s.

The stock status indicator shows a decrease beginning around 2008 with a more rapid decline between 2014 and 2017. This period of strong decline would be linked to a decrease in the productivity of the stock possibly due to rapid environmental changes in the deep waters of the GSL since 2010 (Duplisea et al. 2021a). These unfavorable changes for the Greenland halibut include, among other things, an increase in deep water temperature, a decrease in the level of dissolved oxygen and the massive recruitment of redfish species (*Sebastes mentella* and *S. fasciatus*) representing potential competitors.

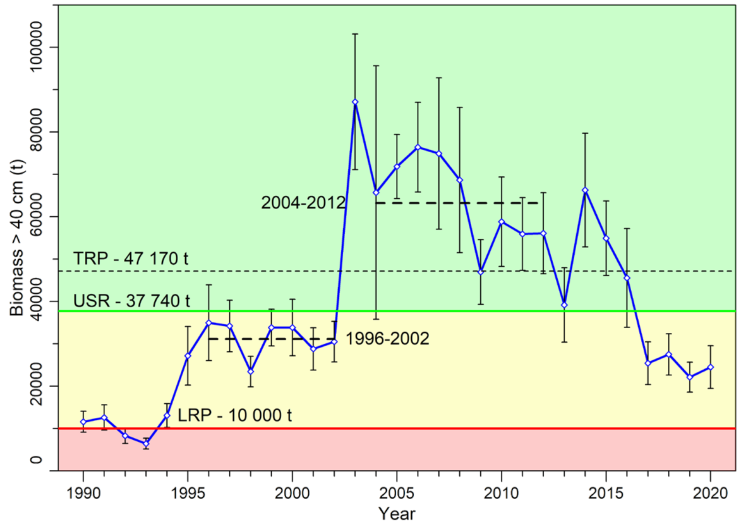


*Figure 1: Greenland halibut > 40 cm biomass index from the nGSL survey. The error bars indicate the 95% confidence interval. The red horizontal line locates the limit reference point (LRP) as part of the precautionary approach and delineates the critical (light red) zone of the caution zone (yellow). The green horizontal line locates the upper stock reference point (USR) and delineates the cautious zone of the healthy zone (green). The dashed black line indicates the target reference point (TRP), which is an approximation of biomass at maximum sustainable yield (Bmsy; average of reference periods 1996-2002 and 2004-2012).*

Recent work showing the long-term impacts of climate change on stock production suggests that a USR based on the biomass during the high productivity period of 2004-2012 may no longer be achievable, even with no fishing mortality (Duplisea et al. 2021b). Another proposed USR was formulated based on the biomass from 1996-2002, that was not the result of a single unusually large recruitment event and could be considered more realistic for the stock. However, since the environmental conditions of the GSL are currently in a state of change, it was unclear if the proposed USR was the most appropriate for the stock.

Taking the state of the GSL into consideration, an additional USR was proposed that will take into account the significant ecosystem changes currently occurring in the GSL as well as the declining productivity of the stock. This new USR is based on the distinct productivity periods of the stock, the 1996-2002 average productivity period and the 2004-2012 high productivity period (Figure 1). According to this proposal, an approximation of the biomass at the maximum sustainable yield ($B_{msy}$) represents the average of the biomasses of these two periods of 47,170 t and the USR corresponds to 80% of this $B_{msy}$ or 37,740 t (Figure 1). $B_{msy}$ is considered the target reference point (TRP) in this proposed precautionary approach.

The development of this precautionary approach is based on the best available data and on the basis that the lack of scientific information cannot hinder the adoption of measures to avoid serious harm to the resource. The TRP, LRP and USR should be reassessed and updated appropriately through future stock assessments with new available information.

At the February 2020 working group workshop, the working group accepted the USR proposal at 37,740 t and the TRP at 47,170 t. The USR and TRP were subsequently presented to the Gulf Groundfish Advisory Committee (GGAC) in the spring of 2021. A consultation with GGAC members took place in the fall of 2021 on the components of the precautionary approach, including the currently proposed reference points (USR and TRP). There was no objection to them. Thus, the GSL Greenland halibut stock precautionary approach framework is currently defined by a LRP at 10,000 t delineating the critical zone from the cautious zone and a USR at 37,740 t delineating the cautious zone from the healthy zone (Figure 1).

The stock status indicator showed a declining trend, decreasing over 60% between 2008 and 2017 and moving from the healthy zone into the cautious zone. The indicator was relatively stable from 2017 to 2020 and shows that the stock is in the cautious zone, at the mid-point between the LRP and the USR.

**Basis of proposed HCR**

HCR can be developed in accordance with PA principles using the stock biomass indicator and reference exploitation rates (DFO 2009). In this case, it was agreed to develop “status-based” type HCR, where projected exploitation rates and corresponding removals are a function of stock status (Kronlund et al. 2014).

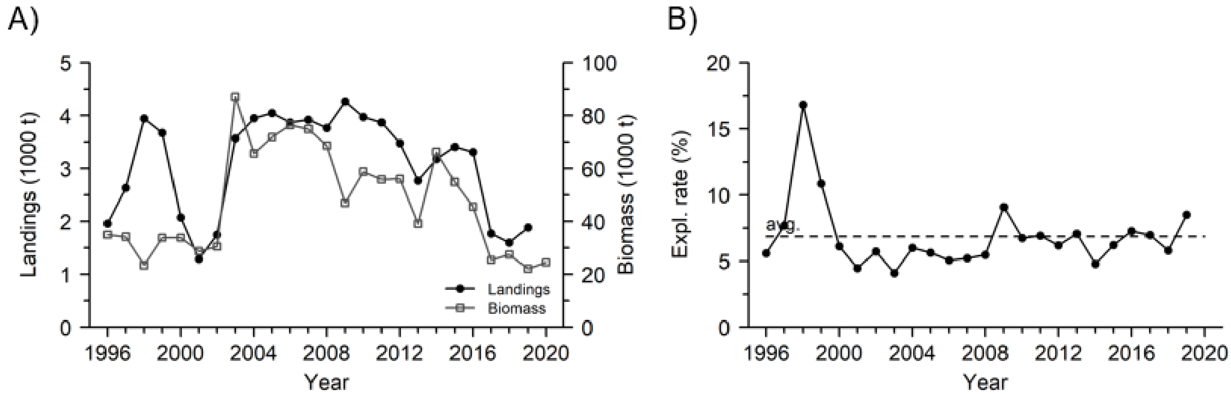


*Figure 2: A) Evolution of commercial landings of Greenland halibut relative to available > 40 cm fish biomass calculated from nGSL survey and B) relative exploitation rate of the 4RST Greenland halibut stock.*

The maximum reference exploitation rate was determined from a relative index of the annual (management year) exploitation rate, obtained by dividing the weight of total commercial Greenland halibut landings by the biomass of > 40 cm fish estimated from DFO nGSL science survey data (Figure 2). These relative exploitation rates (hereafter referred to as exploitation rates) have been available since 1996, when fishing was regulated by a net mesh size of 6 inches (152 mm) and a minimum legal size (42 cm in 1996 and 44 cm thereafter). Although exploitation rates could be calculated before 1996, they would not be comparable to the 1996-2020 period since the commercial fishery was then exploiting a different size range of the stock.

Reference periods were identified according to the trajectory (growth, stability and decline) of the stock status indicator and the average exploitation rates (arithmetic mean) were calculated for each (Table 3). According to the different reference periods, the average exploitation rate varied from 5.31% to 6.75% (Table 3). As a general rule, the highest exploitation rates are observed for periods of decline of the indicator (6.27 to 6.34%), are variable for stable periods (5.49 to 6.75%) and the lowest average exploitation rate is observed during the growth period (5.31%). The maximum reference exploitation rate was defined as the arithmetic mean of the average exploitation rates for the 1996-2002 (excluding 1998) and 2004-2012 periods, which are the periods used to define the TRP and USR (DFO 2021b), and corresponds to 6.51%.

*Table 3: Stock trajectory, average annual exploitation rate and standard deviation for different reference periods.*

| Period | Stock trajectory | Mean expl. rate | Standard deviation |
|---|---|---|---|
| 2002-2006 | Growth | 5.31 | 0.76 |
| 2004-2008 | Stable | 5.49 | 0.37 |
| 2010-2015 | Stable | 6.33 | 0.83 |
| 2004-2017 | Decrease | 6.34 | 1.13 |
| 2014-2017 | Decrease | 6.31 | 1.10 |
| 1996-2002[1] | Stable | 6.75 | 2.26 |
| 2004-2012 | Decrease[2] | 6.27 | 1.24 |

[1] Excluding 1998.

[2] Period during which the indicator decreased but stock productivity was considered high.

### Proposed HCRs

The proposed HCRs determine the exploitation rate based on the stock status indicator. In the cautious and healthy zones, the projected exploitation rates include all reported removal sources. This exploitation rate is then converted to a projected removal, a recommended harvest limit. The determination of the TAC is a fisheries management matter and will not be addressed in this document.

The fisheries decision-making framework incorporating the precautionary approach (DFO 2009) states that in the healthy zone, the exploitation rate must not exceed the pre-established maximum removal level and the management measures must respond to a downward trend when the stock status approaches the cautious zone. In this sense, an operational control point for HCRs has been established at the TRP. The three proposed HCRs apply the maximum reference exploitation rate (6.51%) when the stock status is ≥ TRP. HCRs do not project removals beyond a biomass of 76,805 t (5,000 t / 6.51%) as the stock has never been able to sustain annual landings of more than 5,000 t in the past (Gauthier et al. 2021).

In the cautious zone, the decision framework states that the exploitation rate must increase gradually until the predetermined maximum level is reached and should support the recovery of the stock to return to the healthy zone. Management measures must promote stock growth in the short term. If the stock is in the lower part of the area, the risk tolerance for a preventable decline is very low to low. In this sense, for the different proposed HCRs, the exploitation rate decreases in proportion to the decrease of the stock status, from 6.51% at the TRP to 5.31% at the USR or from 6.51% at the TRP to 5.31% in the middle of the cautious zone, and decreases are extended until the LRP is reached. The value of 5.31% is the average exploitation rate during the stock growth period (Table 3). The average exploitation rate used for this objective is subject to change with new stock data and further assessment.

In the critical zone, it is proposed that no directed fishing will be permitted and bycatch will be maintained at the minimum possible level under the proposed HCRs. In addition, changes to the *Fisheries Act* in 2019 require that a recovery plan be put in place when a stock reaches the critical zone. The latter should allow, with a high probability, the progression of the stock out of the critical zone within a reasonable time.

#### Proposal 1

In this first proposal, the exploitation rate for any stock status ≥ TRP is set at 6.51%, the exploitation rate at the USR is set at 5.31% and a straight line is drawn to link these coordinates (Figure 3). By extrapolating this line, the exploitation rate corresponding to the LRP is 1.78%. For all three proposals, the projected withdrawals are determined by multiplying the exploitation rates on this line by the stock status indicator. In the cautious zone, the projected removals are all lower than the historically observed removals (Figure 3). The equations to determine exploitation rate and removals based on stock status are provided in Table 4 of Annex 1.

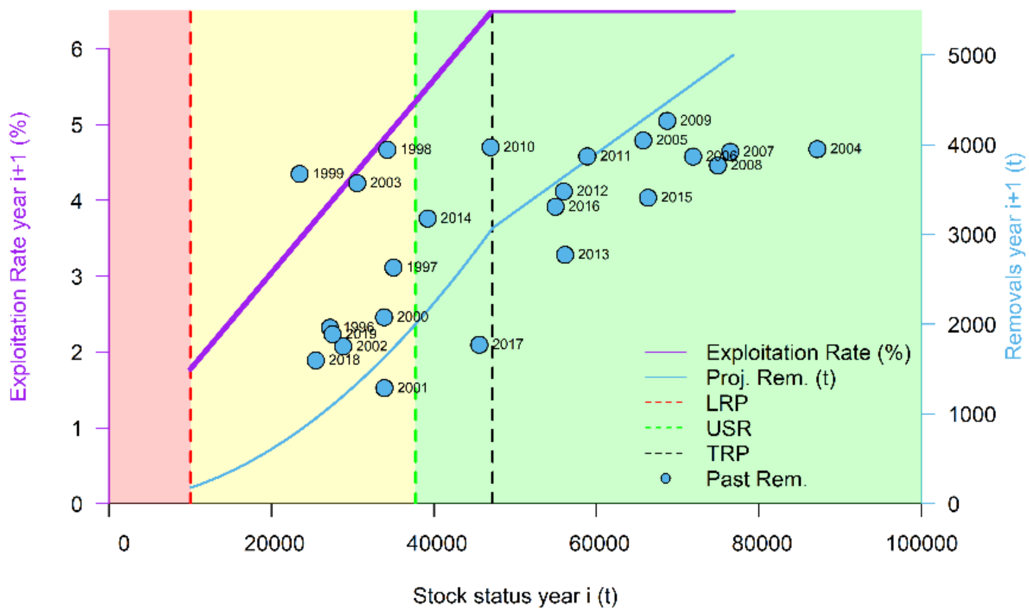


*Figure 3: Illustration of the first HCR proposal. The red, yellow and green regions correspond respectively to the critical, cautious and healthy zones. The purple and blue lines correspond respectively to the exploitation rate and the projected removals (Proj. Rem.). The blue dots represent the removals observed in the past (Past Rem.) as a function of the previous year stock status indicator (the year indicated at each point corresponds to the year of the removal).*

### Proposal 2

In this second proposal, the exploitation rate for any stock status ≥ TRP is set at 6.51%, while the exploitation rate in the middle of the cautious zone, which is the average of the LRP and USR, is set at 5.31%. Exploitation rates at the TRP and in the middle of the cautious zone are then converted to removals and a straight line is drawn to link these coordinates and then extrapolated to the LRP. The removals on the line are then converted into exploitation rates. The result is a curvilinear decrease in exploitation rates in the cautious zone as the stock status indicator approaches the LRP (Figure 4). The exploitation rate corresponding to the LRP is 1.94%. A defining feature of this HCR is a more gradual decrease of the exploitation rate in the upper half of the cautious zone when compared to the exploitation rate reduction from mid-cautious zone approaching the LRP. In addition, almost all historical removals in the cautious zone are higher than the removals projected by this proposal.

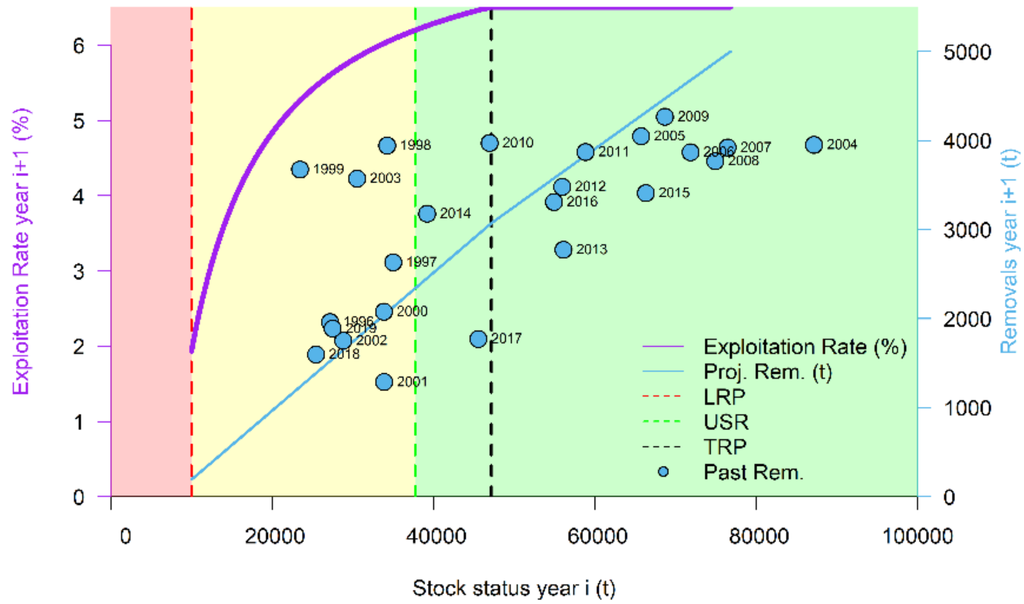


*Figure 4: Illustration of the second HCR proposal. See Figure 3 for details.*

### Proposal 3

Under the third HCR proposal, the exploitation rate for any stock status ≥ TRP is set at 6.51%, the exploitation rate in the middle of the cautious zone is set at 5.31% and a straight line is drawn to link these coordinates and is extrapolated to the LRP. The LRP exploitation rate is 4.59% (Figure 5). Removals are determined by multiplying the exploitation rates on this line by the stock status indicator. In the cautious zone, almost all historical removals in the cautious zone are higher than the removals projected by this proposal.

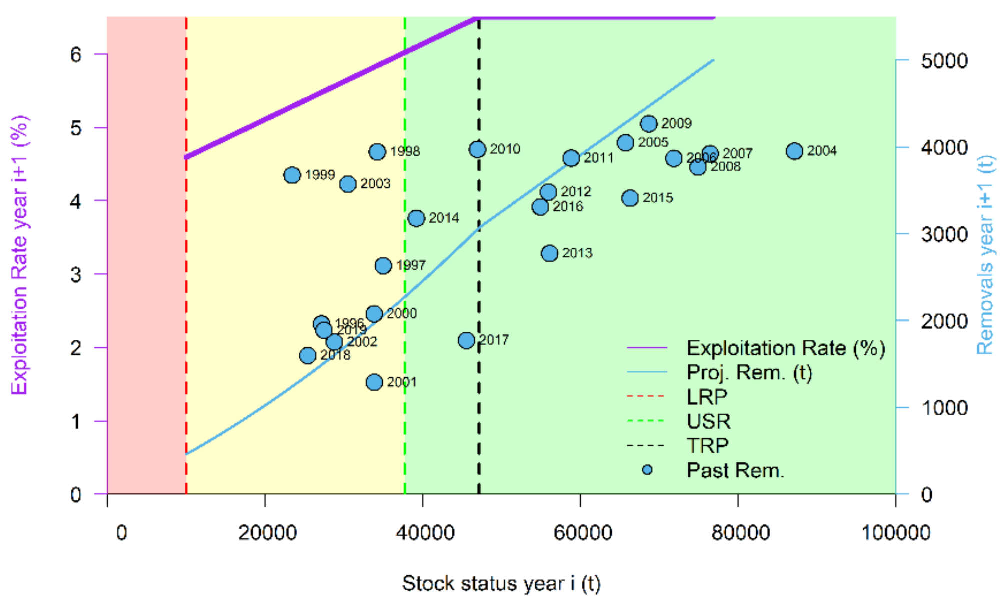


*Figure 5: Illustration of the third HCR proposal. See Figure 3 for details.*

### Comparison of Proposed HCR

The first HCR proposal is considered to be the most conservative since the decline in exploitation rate as the stock declines in the cautious zone is the strongest of the 3 proposals. In addition, exploitation rates in the cautious zone are always below the exploitation rate that would support stock growth and projected removals are generally lower than those observed in the past for equivalent stock sizes (Figures 3 and 6). The second proposal projects removals similar to proposal 3 between the middle of the cautious zone and the TRP (Figure 6), with the maximum difference between the projected removals under proposals 2 and 3 corresponding to 70.0 t (0.20% in terms of exploitation rate). In the lower part of the cautious zone, proposal 2 projected removals are lower than that of proposal 3, with the maximum difference between projected under the two proposals corresponding to 265.7 t (2.66% in terms of exploitation rate). In the present document, proposal 2 is therefore considered to be more cautious and more consistent with the revised *Fisheries Act* (2019) than proposal 3.

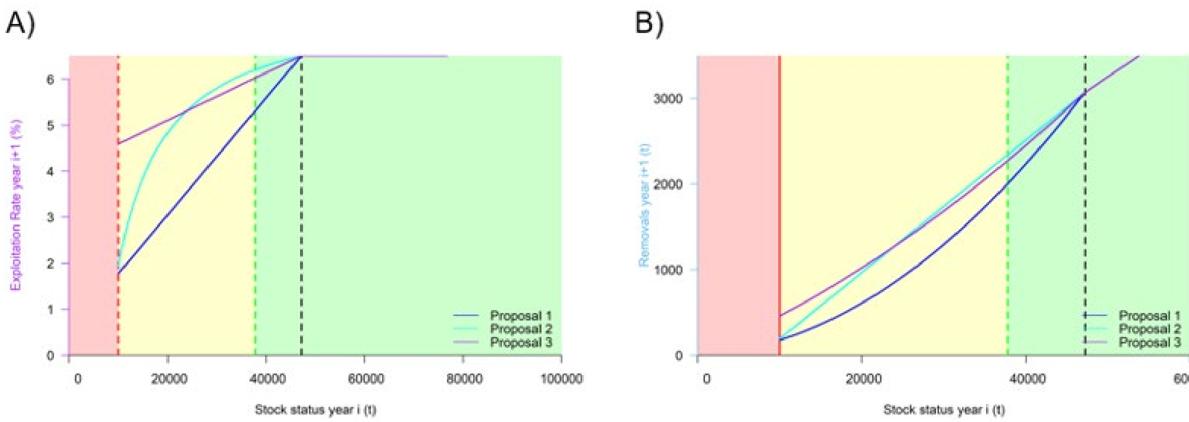


*Figure 6: Comparison of RCP 1, 2 and 3 proposals in terms of A) exploitation rate and B) removals. See Figure 3 for a description of the coloured regions and the hatched vertical lines.*

All three proposals are consistent with the Precautionary Approach Policy (DFO 2009) for fisheries management as:

- In the critical zone, removals are kept to an absolute minimum.
- In the cautious zone, HCRs decrease the exploitation rate as a function of the decrease in the stock status indicator.
- Exploitation rates do not exceed the maximum reference value.

However, it is reasonable to assume that proposals 1 and 2 are more consistent with the revised Fisheries Act (2019) than Proposal 3 since the “LRP should be avoided with high probability to reduce the risk of serious harm and management actions to prevent further decline in stock status should be implemented before this point is reached” (DFO 2021a).

The probability of stock status decline in the cautious zone and impact of management actions to stop it and promote growth to the healthy zone could not be quantified. However, for all three HCRs, the exploitation rate decreases in the cautious zone and corresponds to values that would promote growth in the lower part or in the entire cautious zone. Also, the projected removals by all 3 HCRs in the cautious zone are lower than landings observed in the past, with the exception of 2001. Since landings rarely reach the TAC (only once in the last 30 years), this means that all 3 proposed HCRs are more cautious than the previous management measures.

**Minimization of TAC inter-annual variation**

One of the objectives put forward by the working group was to minimise TAC inter-annual variation, with the aim of bringing a certain degree of economic stability to the various stakeholders involved in the Greenland halibut fishing industry. Different ways of achieving this objective include the use of stair-like HCRs, the use of a smoothed indicator, the use of a two-year TAC, and the determination of a maximum variation in TAC.

Stair-like HCRs, that is constant removals by stock status indicator intervals, can provide some stability in TAC when the stock status does not fluctuate significantly. In the interval where TAC is constant, the exploitation rate increases when the stock status indicator decreases, which could be considered undesirable. In addition, a significant variation in the TAC is observed when the indicator changes interval. This approach was discussed by the working group at the first meetings and the idea was subsequently abandoned.

A smoothed indicator of stock status corresponding to the two-year moving average (average of years *t* and *t*-1; Figure 7) could be used to determine the exploitation rate and projected removals. The choice of a two-year window is based on the fact that 1) the stock status indicator has sometimes shown large inter-annual variations that have been confirmed over time and 2) a three-year window could lead to a significant lag between the smoothed indicator and the HCR projected removals. There are advantages and disadvantages to using this method. When the stock is growing, the use of the smoothed indicator implies that the increase in the exploitation rate and projected removals is less than if the current year indicator was used. On the other hand, when the stock is declining, the smoothed indicator is slower to react and projects higher exploitation rates and removals than those projected by the gross indicator. In the event of a significant decline in stock status, this could lead to less cautious removals with regards to the stock status.

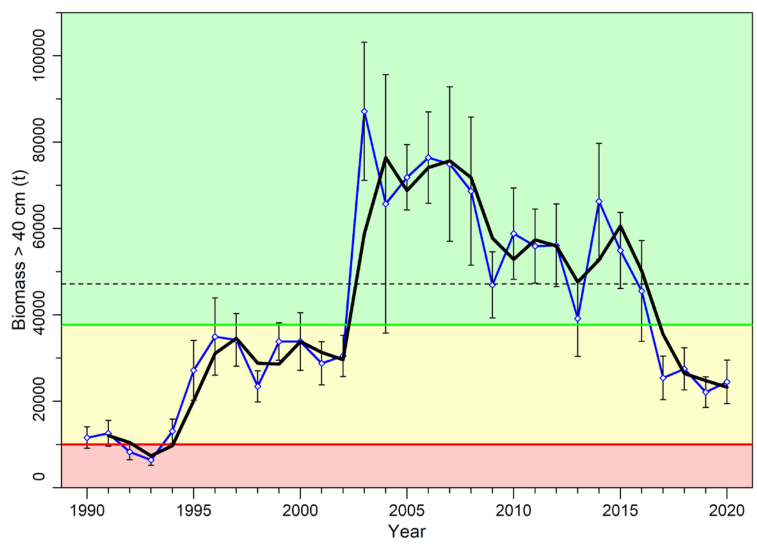


*Figure 7: Annual (white circles, blue line and 95% confidence intervals) and smoothed (two-year moving average; black line) stock status indicator.*

The use of a two-year TAC, as well as the use of the smoothed indicator, can lead to situations where a low TAC is maintained while the stock shows a sudden increase, or a high TAC is maintained while the stock shows a significant decline. In the first situation, this proposal would be considered cautious whereas the opposite would be the case in the second.

The use of a minimum and maximum variation in TAC could also be considered to achieve this objective. For example, in the case of the northern shrimp (*Pandalus borealis*) stocks of the estuary and the GSL, if the difference between the TAC and the projected removal is less than 5%, no TAC adjustment is made. If the stock is in the healthy zone and the difference between the TAC and the projected removal is more than 5%, the TAC adjustment (increase or decrease) will not be greater than 15% (Bourdages et al. 2020). The performance of this type of HCR has been tested in different simulation scenarios using an operational model (Desgagnés and Savard 2012).

Some members of the working group suggested an approach combining the use of the smoothed indicator and a fixed two-year TAC when the gross indicator places the stock in the healthy zone. In the cautious zone, they propose to use an annual TAC adjustment based on the last year's indicator.

It is not possible to simulate the impact of the use of the smoothed indicator, a two-year TAC or HCR involving minimum and maximum TAC variation values in the absence of a population dynamics model for this stock.

### Interim years and unforeseen circumstances

The GSL Greenland halibut stock is assessed and managed on a two-year cycle. In interim years, an update of key status indicators will continue to be prepared to provide resource management with an overview of the most recent stock status. The indicators used to monitor the status of the stock are landings, DFO survey abundance indices (including the index used in the selected HCRs) and the relative exploitation rate of the commercial fishery.

In the event that the nGSL survey is not completed and the stock status indicator could not be estimated, the exploitation rate and projected removals would then be determined with the most recent value of the indicator.

Mechanisms for exceptional circumstances related to a significant fluctuation in the stock status indicator relative to the previous year may be identified as required during the next Greenland halibut stock assessment based on the PA to be selected by Fisheries Management.

### Ecosystem considerations and stock productivity

The GSL has shown significant changes in environmental and ecological conditions since about 2010 such as warming of deep water temperature (Galbraith et al. 2021), declining of northern shrimp biomass (Bourdages et al. 2020) and massive recruitment of competitive redfish species (Senay et al. 2021). These ecosystem changes have likely played an important role in the decline of Greenland halibut biomass and productivity. Greenland halibut is a stenothermic species that has evolutionarily adapted to live within a relatively narrow thermal window. Warming deep water temperatures are expected to reduce their high-density habitat by 49% (Stortini et al. 2017), which will necessarily affect the overall size of the stock. Adverse ecosystem conditions will also affect stock productivity. Notwithstanding the fact that two distinct periods of productivity were considered in the establishment of the USR (and in the definition of the cautious zone), the concept of additional risk related to adverse environmental conditions was not considered in the development of the HCR.

Overall stock productivity is the net total impact of changes in recruitment, growth, sexual maturation and natural mortality. Changes in the GSL environment may affect each process differently. The slow growth in the 2013 cohort observed in 2015 may have been in part the result of these changes, while natural mortality is difficult to know, except retrospectively or using more specific data than those currently available. The impact of temperature changes on stock net production (surplus production) has been studied empirically and shows a dome-shaped relationship (Duplisea et al. 2021b), where Greenland halibut production is maximized at intermediate temperatures while it declines under warmer and colder conditions. This response is typical for a stenothermic species. Using such a relationship, it has been shown that given the current warming levels observed in GSL waters, Greenland halibut production could decrease significantly, negatively affecting sustainable harvest levels. This overall production impact caused by climate warming is the result of a scenario-based approach that can generally capture production dynamics even if it cannot separate direct causes and their specific impacts on the individual production processes.

# Conclusions

All the necessary elements for the implementation of a comprehensive precautionary approach for GSL Greenland halibut are presented in this document: a stock status indicator, limit, upper stock and target reference points, reference exploitation rate and scenarios (3) of harvest control rules. Conservation objectives were also presented.

All three HCR proposals are consistent with the Precautionary Approach Policy (DFO 2009) for fisheries management as:

- In the critical zone, removals are kept to an absolute minimum.
- In the cautious zone, HCRs decrease the exploitation rate as a function of the decrease in the stock status indicator.
- Exploitation rates do not exceed the maximum reference value.

Different strategies to reduce TAC inter-annual variations were presented, such as the use of the smoothed indicator and a fixed two-year TAC. These could be used with the selected HCR.

The choice of one HCR proposal over another is hardly scientifically justifiable in the absence of quantitative tools to test the performance of each HCR. However, if one of the 3 HCRs had been used in the past 5 years, the projected removals would have been more conservative than previous decisions made when the stock was in the cautious zone. The past 4 years decisions enabled the short-term objective to be achieved (stop the decline). Future work will seek to develop a population dynamics model that will test existing or future HCRs and take into account the risks associated with the changing environment in which the GSL Greenland halibut stock is currently evolving. This work may result in changes to the PA components.

The elements of the PA including the selected harvest control rule will be implemented by the resource management. Similarly, the TAC will be determined by resource management from the HCR projected removals based on the selected PA decision rule.

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# Appendix 1

*Table 4: Equations for calculating exploitation rates (E, between 0 and 1) and removals (R, in tonnes) projected by different HCR proposals for cautious and healthy zones, based on the stock status indicator (I).*

| HCR | Equations cautious and healthy (≤ TRP) zones | Equations healthy zone ≥ TRP |
|---|---|---|
| Proposal 1 | $m = 1.273436e^{-6}; b = 5{,}030728e^{-3}$<br>$E = m * I + b$<br>$R = (m * I + b) * I$ | $E = 0.0651$<br>$R = E * I$ |
| Proposal 2 | $m = 7.740305e^{-2}; b = -580.3473$<br>$E = \frac{m * I + b}{I}$<br>$R = m * I + b$ | $E = 0.0651$<br>$R = E * I$ |
| Proposal 3 | $m = 5.154191e^{-7}; b = 4.078717e^{-2}$<br>$E = m * I + b$<br>$R = (m * I + b) * I$ | $E = 0.0651$<br>$R = E * I$ |

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