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Spawning stock biomass reference points for spring and fall spawning herring in the southern Gulf of St. Lawrence

Niveaux de référence de biomasse reproductrice pour les harengs géniteurs de printemps et d’automne dans le sud du Golfe du Saint-Laurent

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Abstract

Spawning stock biomass reference points consistent with the Precautionary Approach were derived for the spring and fall spawning components of southern Gulf of St. Lawrence herring. The two reference points are the Limit Reference Point (LRP) and the Upper Stock Reference (USR). Below the level of spawning biomass corresponding to the LRP, removals from the stock should be kept to the lowest possible while between the LRP and the USR, the removal rate should be lower than the removal rate reference. Above the USR, the removal rate should not exceed the removal rate reference. Stock and recruitment data for the two components were fitted to Beverton-Holt and Ricker stock-recruit models to determine if the two models can be used to identify the LRP. However, the model fits were poor. Given high recruit per spawning biomass ratios when the two components recovered, appropriate LRPs for the two components were calculated as the average of the 4 lowest biomass estimates, which occurred about the late 1970's and early 1980's. LRPs for the spring and fall components were 22,000 t and 51,000 t, respectively. To determine the USR, expected spawning stock biomass assuming average recruitment (age 2) and the removal rate reference ($F_{0.1}$; 0.35 for the spring component and 0.32 for the fall component) were calculated using spawner per recruit analyses. Interim values for the USR for the spring and fall components were 54,000 t and 172,000 t, respectively.

Résumé

Nous avons établi des points de référence pour la biomasse du stock reproducteur (BSR) de hareng du sud du golfe du Saint-Laurent, conformes à l'approche de précaution, pour les composantes de reproducteurs de printemps et d'automne, soit le niveau de référence limite (NRL) et le niveau de référence supérieur (NRS). Sous le niveau de la BSR correspondant au NRL, les captures dans le stock devraient être maintenues au plus faible niveau possible; lorsque la BSR se situe entre le NRL et le NRS, le taux d'exploitation devrait être maintenu à un niveau inférieur au taux d'exploitation de référence; et lorsque la BSR se situe au-dessus du NRS, le taux d'exploitation ne devrait pas dépasser le taux d'exploitation de référence. Nous avons introduit des données sur le stock et le recrutement pour les deux composantes de reproducteurs dans des modèles stock-recrues de Beverton-Holt et de Ricker en vue d'établir si elles pouvaient servir à établir le NRL. L'ajustement des modèles n'était cependant pas très bon. Étant donné les fortes proportions de recrues par rapport à la biomasse de reproducteurs lorsque les deux composantes se sont rétablies, nous avons établi des NRL appropriés pour chacune en calculant la moyenne des quatre biomasses estimatives les plus basses, qui se sont produites vers la fin des années 70 et au début des années 80, ce qui a donné des valeurs respectives de 22 000 t et de 51 000 t. Pour établir le NRS pour les deux composantes, nous avons fait des analyses de la biomasse du stock reproducteur par recrue pour obtenir le taux d'exploitation de référence (F0.1 = 0,35 pour la composante des reproducteurs de printemps et 0,32 pour la composante des reproducteurs d'automne), et la BSR prévue si le recrutement se produit à un âge moyen (âge 2), ce qui a donné des valeurs provisoires respectives de 54 000 t et 172 000 t.

Introduction

Herring has been an important fishery in the southern Gulf of St. Lawrence (NAFO 4T) for several decades. This resource is exploited by both inshore fishermen using fixed gears and by larger vessels using purse seines. Prior to 1967, herring were exploited primarily by gillnets and landings over the period 1935 to 1966 averaged 34,000 t (LeBlanc et al. 2005). In the mid 1960's, a purse seine fishery was introduced and landings increased substantially, reaching 272,000 in 4T. Tagging studies conducted in the late 1960's and early 1970's indicated that at least a part of the spring and fall herring components from the southern Gulf overwintered off southwest Newfoundland (NAFO 3Pn; Winters and Beckett 1978) and important catches were made in the area. Therefore, landings from the two components were likely higher than recorded. Landings declined to between 40,000 and 50,000 t until the stock collapsed in the late 1970's (Fig. 1). During the 1980's, the resource recovered and landings increased. Over the last 20 years, landings have averaged 65,000 t annually. Because herring in the southern Gulf of St. Lawrence comprise both a spring spawning and a fall spawning component, it is important to examine landings separately. Data on landings separated by spawning component exist since 1978. Landings for the spring component have been in decline for the last 10 years while those for the fall exhibit more stability (Fig. 2).

Since the mid-1980's, stock assessments of each spawning component are conducted annually using virtual population analyses. While the assessment indicates that the fall component remains relatively healthy compared to the 1970's and early 1980's, the spring component has been declining since the mid-1990's. Estimated spawning biomass (ages 4+) for the spring component was about 47,000 t at the beginning of 2005 (Fig. 3). This was above the lowest level estimated during the period 1978 to 2005; however, there is concern that a continued decline could quickly reduce the spawning biomass of this component to levels observed in the early 1980's. Given this situation and in the context of the application of the Precautionary Approach, it was deemed important to examine biological reference points for the two components.

The current management strategy for southern Gulf of St. Lawrence herring restricts the harvest to $F_{0.1}$ or below. The management regime distributes the overall quota among various spawning beds based on historical catches. It should be noted that this distribution may not be optimal to promote conservation. However, while $F_{0.1}$ is generally considered a safe harvesting strategy, the fundamental calculations involved in its determination aim to optimize yield without consideration for the underlying biomass and its ability to produce recruits to replenish the stock. Thus, situations can arise where a stock has declined to a critically low level resulting in impaired productivity. Fishing at $F_{0.1}$ will only serve to exacerbate the situation. Similarly, in cases where natural mortality has increased, yield-per-recruit calculations of $F_{0.1}$ will suggest a higher fishing mortality rate which can quickly result in reductions of the spawning stock to levels where productivity may be impaired. In these cases, the application of the Precautionary Approach requires the identification of biomass reference points to serve as benchmarks to signal changes in harvesting strategy. Changes to the exploitation rate can prevent stock declines to levels where productivity is impaired or, where actions are required, help recover from such declines. The objective of this paper was to determine spawning biomass reference points for the spring and fall spawner components of the southern Gulf of St. Lawrence herring stock.

The Precautionary Approach and reference points

The Precautionary Approach is a general philosophy to manage threats of serious or irreversible harm when there is scientific uncertainty. It can be applied to all kinds of situations from precautions to avoid the spread of contagious diseases, air traffic control and pollution prevention. For the prudent management of fisheries, it requires the following elements:

- Objectives that take into account stock conservation and environmental and ecosystem considerations, as well as the socio-economic performance of the fishery.
- Identification of unacceptable outcomes, such as stock collapse.
- Pre-agreed strategies to achieve objectives while avoiding unacceptable outcomes.
- Taking uncertainties into account.
- Greater caution when knowledge is less complete or less reliable.

In fisheries, the Precautionary Approach has emerged globally as a new framework for management. It results from several developments that culminated in 1995 with an agreement at the United Nations on the conservation and management of straddling stocks and highly migratory fish stocks. This agreement is commonly called the "UN Fish Stock Agreement" (UNFSA). Canada has been a strong proponent of the management principles outlined in this agreement and ratified it in the fall of 1999. The Agreement came into effect December 2001 when it was ratified by 30 countries. Currently, 56 countries have ratified the agreement. The Government of Canada has also elaborated the principles of the Precautionary Approach for decision-making in Canadian public policy in general (Govt. of Canada 2001). Finally, in its policy framework for fisheries management in Atlantic Canada (Fisheries and Oceans 2004), the Department of Fisheries and Oceans committed to use precautionary decision-making approaches consistent with the Oceans Act and the UNFSA.

While the precautionary approach is often invoked, its interpretation as it relates to the harvesting strategy has been sometimes misunderstood. A harvest strategy compliant with the Precautionary Approach would include the adoption of a Limit Reference Point (LRP) and an Upper Stock Reference (USR) which would divide stock abundance into three zones: critical, cautious and healthy (DFO 2005; Fig. 4). When the stock biomass is above the USR, the harvesting strategy would be to fish at or below, but not exceed the removal reference. In the case of southern Gulf herring, $F_{0.1}$ is the removal reference. If the stock biomass declines below the USR, then the removal rate should progressively decrease as the stock level approaches the critical zone with the objective to promote stock growth. If the biomass declines below the LRP, then removals from the stock should be kept to the lowest level possible. Though not essential to the Precautionary Approach, a harvest strategy could also include target reference points of spawning biomass (DFO 2002a). The target reference points can be used to maintain the stock at a level to achieve desired objectives, the latter taking into account a combination of biological and socio-economic considerations. A target reference point would be higher than the USR value.

The definition of the LRP is the stock level below which productivity is sufficiently impaired to cause serious harm because the probability of poor recruitment is high. This level of stock biomass is above the level where the risk of extinction becomes a concern. Myers et al. (1994) conducted an extensive review of limit reference points for recruitment overfishing. In the context of the Canadian Precautionary Approach, this is the biomass level below which would result in serious or irreversible harm. They examined a variety of methods for calculating the LRP and concluded that the ones based on the stock size resulting in 50% of the maximum predicted average recruitment were preferred because they were more robust and could be easily understood. As in Myers et al. (1994), Shelton and Rice (2002) suggest examining a variety of estimation methods as there does not appear to be a single method that can fit all cases.

The USR is defined as the stock level below which the removal rate is reduced. This level will be determined, in part, by productivity objectives for the fishery. In the context of the FAO Code of Conduct for Responsible Fisheries and the UN agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UNFSA), the ICES Comprehensive Fisheries Evaluation Working Group concluded that stock biomass should be kept above the level that will produce maximum sustainable yield (MSY) and thus fishing rate needed to be kept below that which produces that level (Anon. 1996). The harvesting strategy for southern Gulf herring being $F_{0.1}$, which is below $F_{MSY,}$ is consistent with this approach.

Besides conservation, there are other reasons to adopt biomass reference points. Since the mid-1990's, initiatives to certify the sustainability of seafood have taken shape. The Marine Stewardship Council (MSC), based in the UK, has developed criteria to assess whether fish products originate from fisheries that are managed responsibly. Products that meet the criteria of the MSC are awarded a label (eco-labeling) which certifies that the product originates, among other things, from a well-managed fishery. One of the criteria (criterion 3 under principle 2) of the MSC (see www.msc.org/assets/docs/fishery_certification/MSCPrinciples&Criteria.doc) states 'Where exploited populations are depleted, the fishery will be executed such that recovery and rebuilding is allowed to occur to a specified level within specified time frames, consistent with the Precautionary Approach and considering the ability of the population to produce long-term potential yields."

Similarly, Seafood Watch in the U.S., which has similar goals to the MSC, is using B_{MSY} as a reference point to define whether seafood originates from sustainable sources. Thus, if these initiatives become important in the marketing of fish products, it will become advantageous to adopt biomass reference points.

Methods

The analysis of the limit reference point focused on determining the level of spawning biomass below which recruitment might be impaired and thus result in serious and potentially irreversible harm. Stock-recruit relationships were first fitted to the data to calculate the reference points based on the spawning stock biomass producing 50% of the maximum average recruitment following Myers et al. (1994). Both Ricker and Beverton-Holt stock–recruit models were fitted to the data assuming a log-normal error distribution.

The Ricker stock-recruit model is defined as:

$$R_t = \alpha S_{t-r} e^{-\beta S_{t-r}}$$

where S_t= spawning stock biomass in year *t*, *R*= number of recruits, *r* is the age at recruitment and α and β are parameters.

The Beverton-Holt relationship:

$$R_t = \frac{\alpha S_{t-r}}{1 + (S_{t-r} / K)}$$

where *K* is a parameter.

In addition to this reference point, other potential candidates were examined as LRP. A reference point analogous to that proposed by Serebryakov (1991) and Shepherd (1991) was calculated. This corresponds to a low level of stock, which is nevertheless capable of producing an average year-class when conditions are favorable. It is calculated by dividing the median of year-class size by the 90th percentile of survival. Another LRP considered was the lowest spawning stock biomass ($B_{recover}$) from which a secure recovery has occurred in the history of the stock.

Data used in the analyses of stock and recruit were obtained from the most recent assessment document (LeBlanc et al. 2005). For both the spring and fall components, SSB was considered to be the biomass of ages 4 and over (knife-edge maturity ogive used in the stock assessment) and recruitment was considered at age 2. For the spring component, data for the 1978 to 2001 year-classes were used because the youngest age for the index of abundance is age 3 (Table 1, Fig. 5). For the fall component, because the youngest age of the abundance index was age 4, data for the 1978 to 2000 year-classes were used. Because of the retrospective pattern in the fall assessment, analyses were also conducted excluding data after 1998 to determine the influence of retrospective patterns to the fit of the stock-recruit relationship. Removing these points did not affect the fit of the models.

For the USR, the $F_{0.1}$ reference removal rate was first calculated using the yield per recruit method of Thompson and Bell calculations. The average weight and partial recruitment at age were the average of the last 3 years (Table 2). Expected spawning stock biomass assuming average recruitment (age 2) and the removal rate reference were then calculated using spawner per recruit analyses based on the stock component characteristics (vectors of mean weight at age, natural mortality, partial recruitment) for both the spring and fall components. This analysis would not define directly the USR but would bind the value of the USR. The USR would be located somewhere between the LRP and the expected SSB at the removal rate.

Results and Discussion

The stock recruit data for the spring and fall suggested some density-dependent survival. One possible biological reason for this density-dependence is that herring form dense aggregations on spawning grounds and spawning grounds tend to be at specific areas. Spawning bed surveys conducted in the southern Gulf of St. Lawrence have shown that there can be many layers of eggs forming a thick carpet over the substrate. At high population abundance, this could result in several layers of eggs being deposited. In this case, there could be a higher mortality of eggs due to lack of oxygen. This has been documented on Fisherman's Bank in the southern Gulf of St. Lawrence (Messieh and Rosenthal 1989). The fit of the Beverton-Holt stock-recruit relationship was very poor, resulting in an almost horizontal line (Fig. 6). The Ricker stock–recruit relationship was also weak.

For the spring and fall components, the Ricker stock recruitment relationship implied that the levels of spawning stock biomass that would produce half of the maximum average recruitment were 10,500 and 30,000 t respectively (Fig. 6). However, given the poor fit of the stock-recruit relationship to the data, these were not considered appropriate as estimates of the LRP. The reference points indicated by the Serebryakov approach gave higher levels of SSB: 19,500 t and 90,000 t for the spring and fall components. This approach was examined at the National Workshop on reference points for Gadoids (DFO 2002b) and it was noted that the properties of this reference point are not well known. Thus, it was not considered further.

For the spring and fall components, the lowest historical SSB from which the stock was able to recover ($B_{recover}$) were 11,500 and 37,000 t, respectively. The numbers of recruits produced from these low SSB levels were exceptionally high (highest points in Fig. 7) and may have been a compensatory response to low abundance, but additionally could have resulted from favorable biological and environmental conditions prevalent during that period. As such, the high recruitment per SSB ratios observed and the recovery of the stock may not occur at similar low levels of biomass in the future if conditions are less favorable. Thus, a more cautious estimate of the LRP was arbitrarily obtained as the average of the four lowest values of biomass during that time period. This corresponded to 22,000 t (1980 to 1983 average) for the spring component and 51,000 t (1978 to 181 average) for the fall component.

The $F_{0.1}$ reference removal rate implied a fully-recruited fishing mortality of 0.35 for the spring component and 0.32 for the fall component. Expected SSB levels assuming average recruitment (210 and 550 million fish for spring and fall, respectively) and fishing at $F_{0.1}$ were about 54,000 t and 172,000 t for spring and fall, respectively. Spawning stock biomass could be expected to fluctuate around these values and, normally, the USRs would be set somewhere between the LRPs and these expected SSB levels. However, given the uncertainty in the stock and recruitment dynamics of both the spring and fall components of 4T herring, it was considered appropriate to have the USR closer to the expected SSB than to the LRP. The plot of historical values of exploitation rate and SSB showed that except for the first 5 to 6 years of the time series, the SSB estimates for both the spring and fall components were generally above the expected SSB levels (Fig. 8). Consequently, these expected SSB levels were considered to be appropriate interim values for the USR.

Conclusion

For the spring component, the limit reference point and interim upper stock reference proposed are 22,000 and 54,000 t, respectively. For the fall component, the values are 51,000 and 172,000 t, respectively. It is recommended that these reference points be used in the application of a Precautionary Approach framework for southern Gulf of St. Lawrence herring. These reference points should be examined periodically to determine their suitability and revised, if appropriate, given additional information on stock dynamics.

Relative to these reference points, the spawning stock biomass of the fall component is considered to be in the healthy zone in 2005. For the spring component, the spawning stock biomass in 2005 is in the cautious zone. The harvest strategy implied in the cautious zone is to reduce exploitation below the removal reference with the objective of increasing SSB. A number of harvest strategies consistent with this principle are possible. This implies that control rules to reduce the exploitation rate need to be developed in consultation with stakeholders as soon as possible. While the fall component is well above the USR, the control rules should also be developed for this component.

It should be noted that for southern Gulf herring other issues may need to be considered to avoid depleting the stock to levels where the probability of poor recruitment is high. Currently, the management regime distributes the overall quota among various spawning beds based on historical catches. The current distribution may not be optimal to prevent the loss of some spawning components since the allocation is not based on the abundance in that area. Further work on this issue is warranted.

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Table 1. Input parameters for the stock-recruit analyses.

	Spring		Fall	
Year-class	SSB	Recruits – Recrues (000)	SSB	Recruits (000)
1978	82859	53286	57752	322388
1979	56034	214157	40489	493750
1980	30733	280949	36790	684662
1981	14551	303861	68090	373363
1982	11483	366639	104352	498234
1983	30345	165331	148611	734149
1984	51649	108697	217697	465155
1985	80692	143791	246179	287421
1986	117416	173190	273615	317906
1987	113203	222929	314457	1052627
1988	94722	564533	319870	641205
1989	79471	273392	288110	196782
1990	74020	187776	266597	500830
1991	78144	655499	317736	191360
1992	113375	80271	323100	520356
1993	111016	161851	274178	350158
1994	97512	135302	268834	548778
1995	133793	137014	212061	1055992
1996	103497	145903	187252	780607
1997	89378	217984	171875	523046
1998	77128	112393	186592	931371
1999	68223	192776	247343	494754
2000	60623	48228	276847	662019
2001	59285	117911		

Table 2. Input parameters for yield-per-recruit calculations for spring and fall herring. Weights-at-age and partial recruitment values are averages of 2003-2005 data. M= 0.2 for both spring and fall.

	Spring			Fall		
Age	Weight	Partial recruitment	Maturity	Weight	Partial recruitment	Maturity
2	0.105	0.05	0	0.082	0.001	0
3	0.142	0.12	0	0.14	0.06	0
4	0.160	0.43	1	0.197	0.5	1
5	0.183	0.88	1	0.227	1	1
6	0.204	1	1	0.247	1	1
7	0.227	1	1	0.266	1	1
8	0.241	1	1	0.285	1	1
9	0.258	0.89	1	0.306	1	1
10	0.267	0.89	1	0.319	1	1
11	0.289	0.89	1	0.335	1	1
12	0.289	0.89	1	0.349	1	1
13	0.289	0.89	1	0.349	1	1
14+	0.289	0.89	1	0.349	1	1

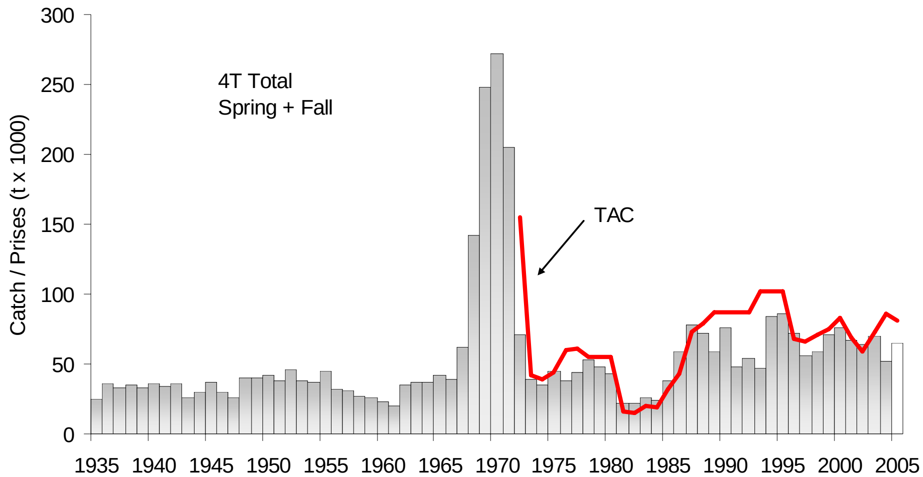

Figure 1. Landings and TAC for southern Gulf of St. Lawrence (4T) herring from 1935 to 2005 (2005 landings are preliminary). Landings do not include catches in NAFO 3Pn prior to 1980, some of these catches may have been from the southern Gulf of St. Lawrence stock.

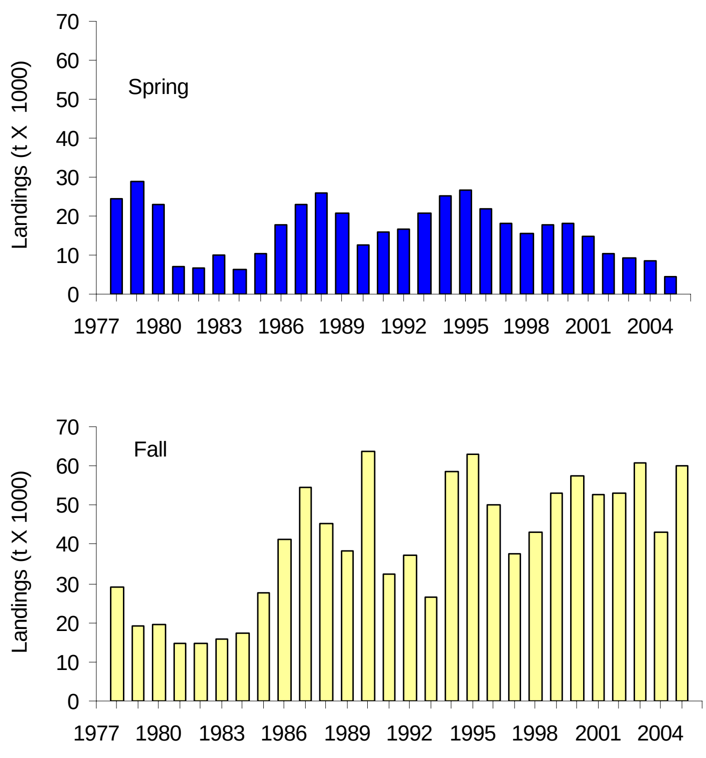

Figure 2. Landings for the spring (top) and fall (bottom) spawning components of southern Gulf of St. Lawrence herring.

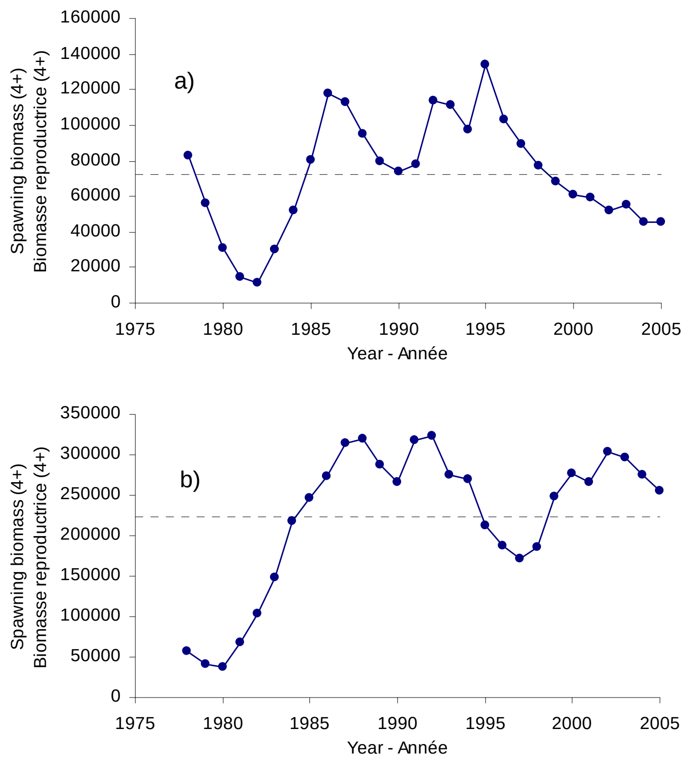

Figure 3. Spawning stock biomass of southern Gulf (NAFO 4T) herring in the period 1978-2005 for the spring spawning component (a) and the fall spawning component (b). The dotted line indicates the average.

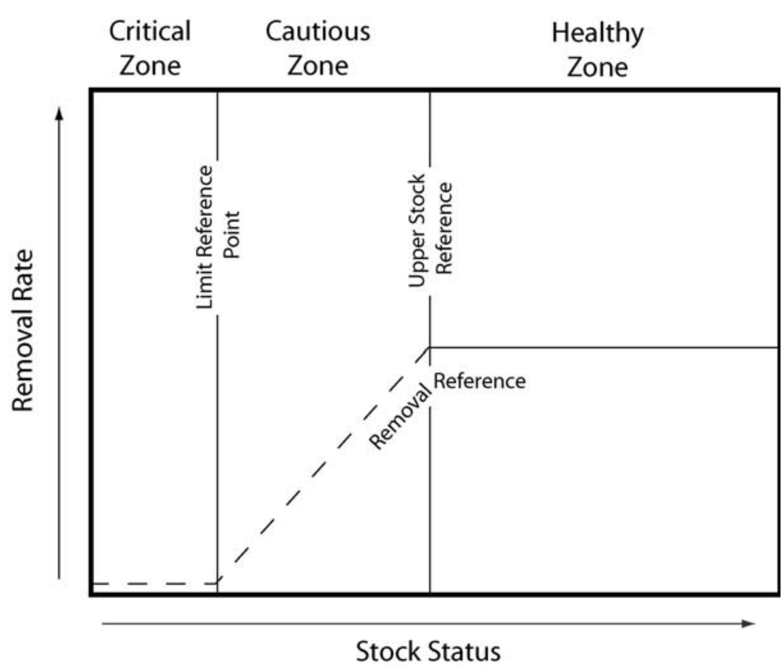

Figure 4. Fisheries management framework consistent with a precautionary approach.

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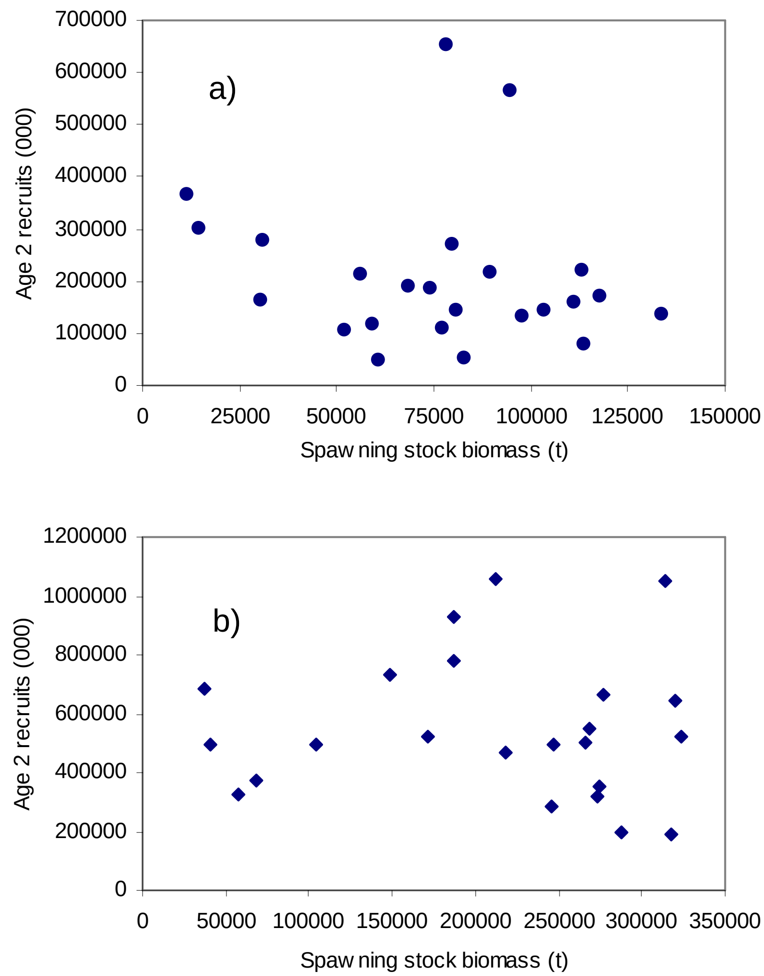
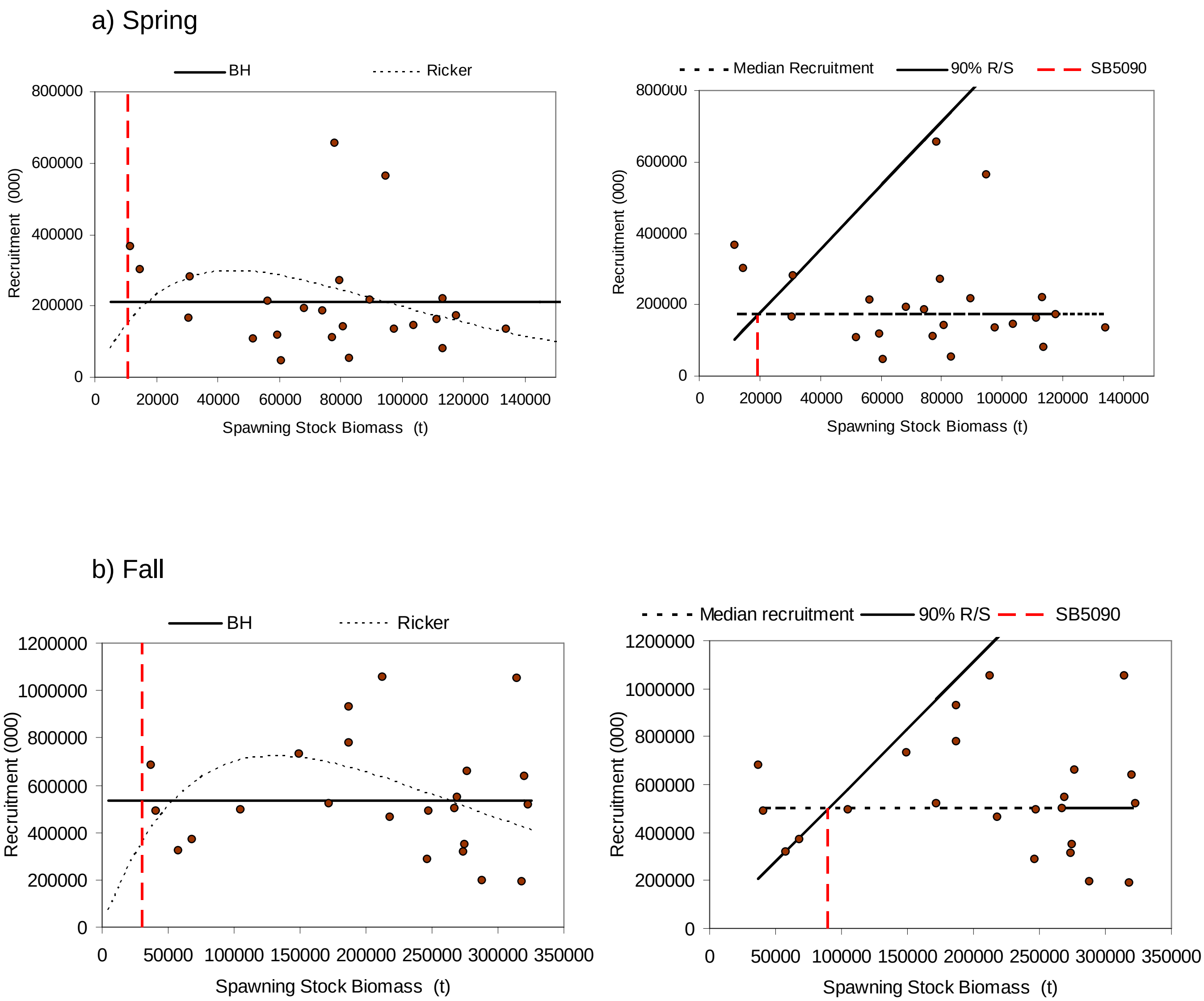


Figure 5. Stock/recruit plot for southern Gulf (NAFO 4T) herring in the period 1978-2001 for the spring spawning component (a) and the fall spawning component (b).



Figurer 6. Beverton-Holt (BH) and Ricker stock-recruit relationships and RK50 reference point (vertical line) for spring and fall spawning components (left panel). The right panel shows the median recruitment, 90% recruit per spawner and the SB5090 reference point (see Serebryakov method in text). The dots indicate the observations of stock and recruits

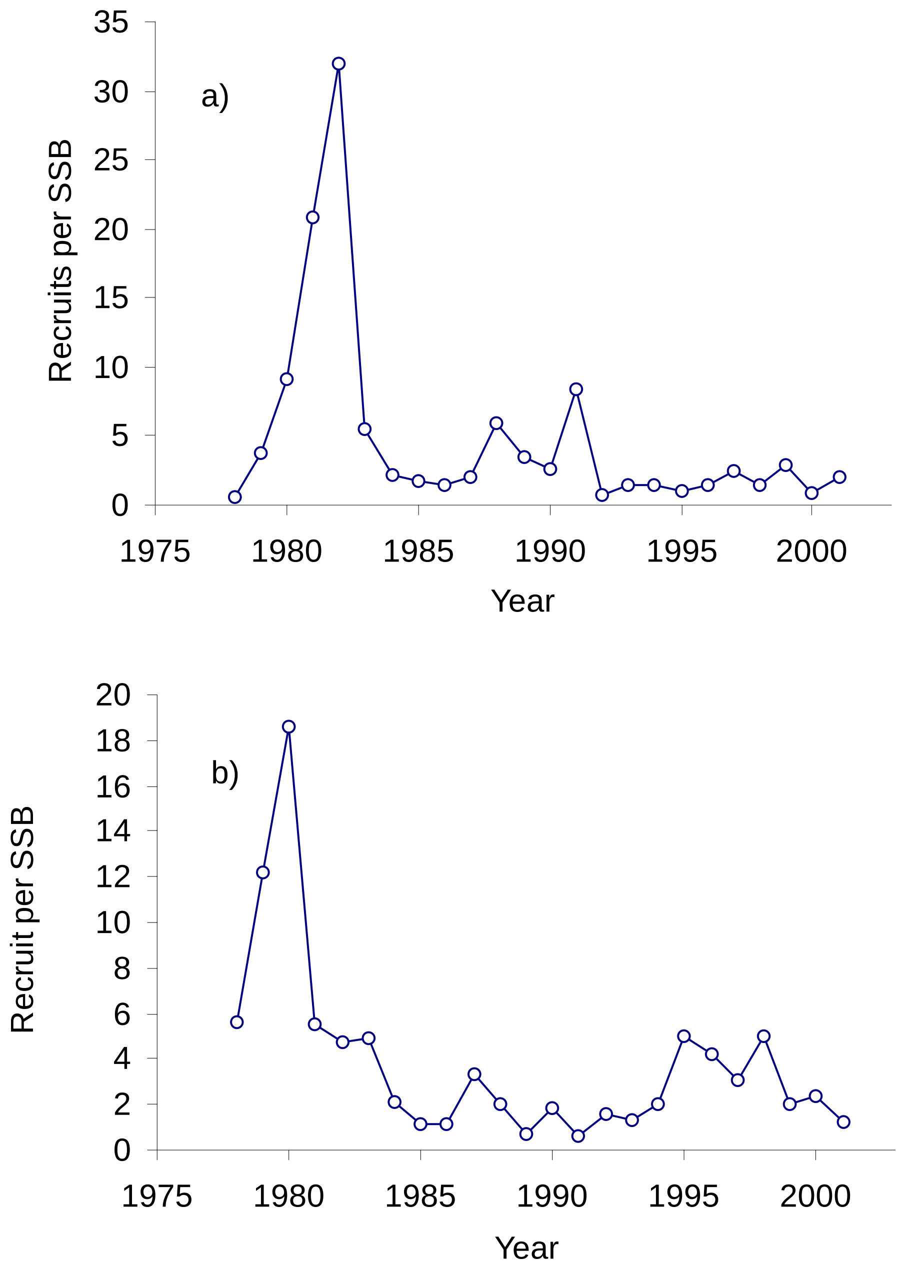
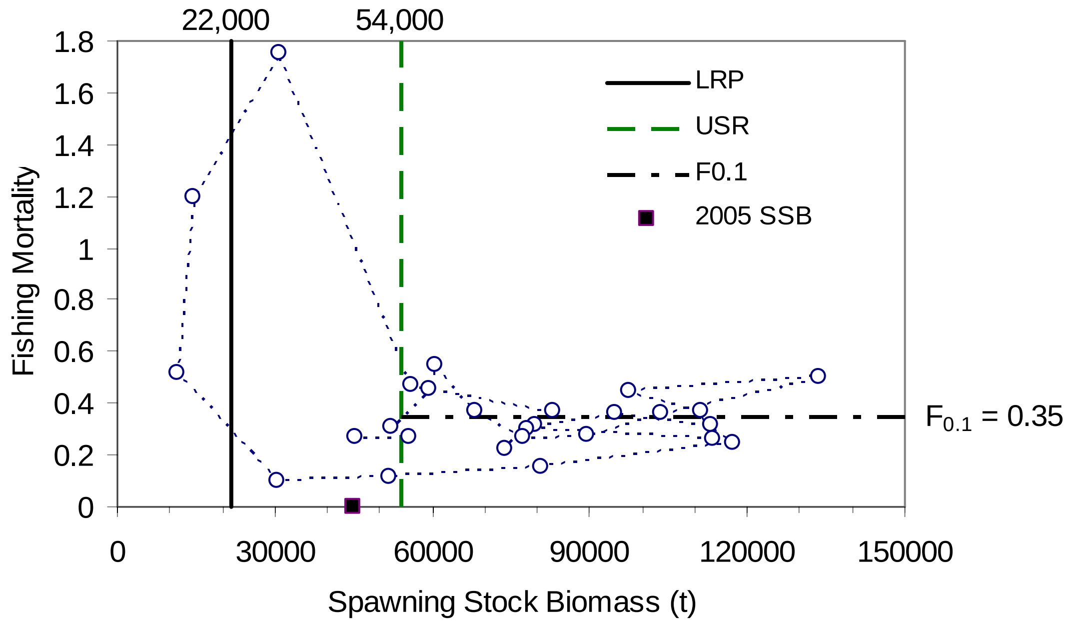


Figure 7. Recruit per SSB plot for southern Gulf (NAFO 4T) herring in the period 1978-2001 for the spring spawning component (a) and the fall spawning component (b).

a) Spring



b) Fall

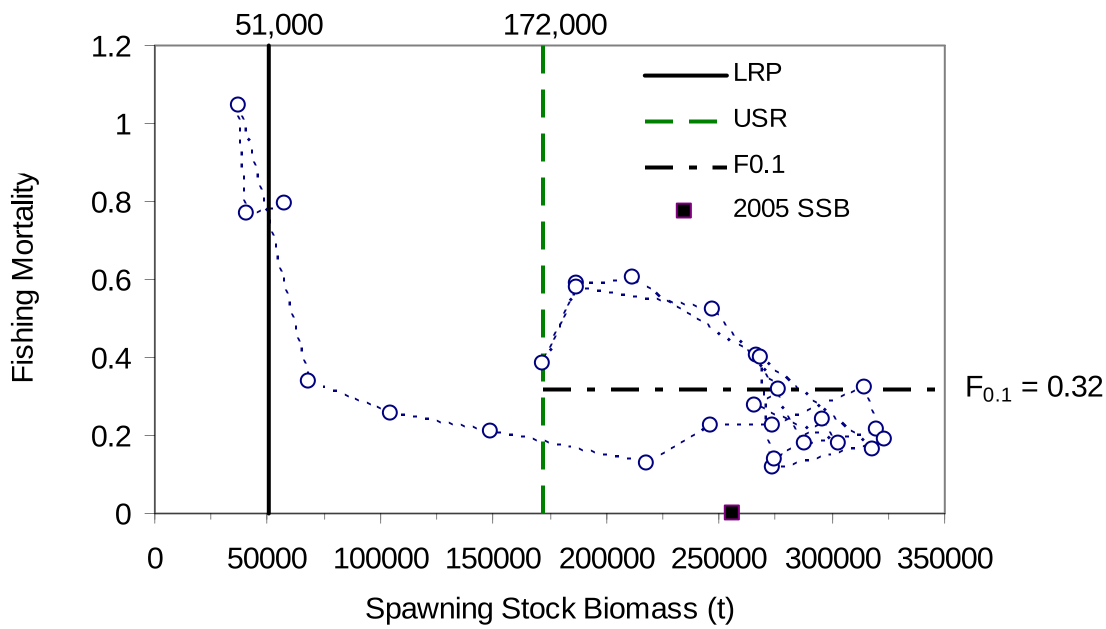


Figure 8. Estimated spawning stock biomass and fishing mortality for the spring and fall components of southern Gulf of St. Lawrence herring for 1978 to 2004 (open circles) and suggested reference points (LRP, USR and $F_{0.1}$). The 2005 estimates of spawning stock biomass are indicated (filled square).