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Canadian Science Advisory Secretariat
Gulf Region | Science Advisory Report 2021/018

REFERENCE POINTS FOR STRIPED BASS (*MORONE SAXATILIS*) FOR THE SOUTHERN GULF OF ST. LAWRENCE POPULATION

*Striped Bass (*Morone saxatilis*)*
Image courtesy of New York State Department of Environmental Conservation

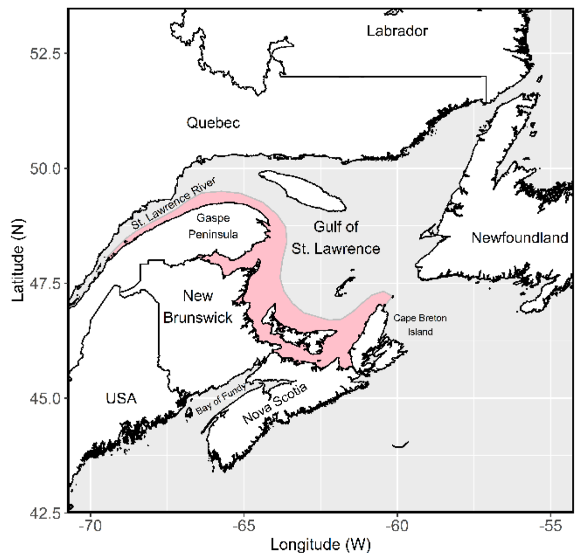

Figure 1. Distribution (coloured polygon) of the southern Gulf of St. Lawrence population of Striped Bass in eastern Canada.

Context:

*The Striped Bass (*Morone saxatilis*) population of the southern Gulf of St. Lawrence had declined to less than 5,000 spawners in the late 1990s. Due to conservation concerns, the commercial fishery closed in 1996, followed by the closure of the recreational fisheries and the suspension of Indigenous Food, Social, and Ceremonial (FSC) fisheries allocations for Striped Bass in 2000. The Striped Bass population of the southern Gulf, located at the northern distribution of the species range in eastern North America, is widely distributed in estuaries and coastal waters from the northern tip of Cape Breton Island, Nova Scotia to the north shore of the Gaspe Peninsula, Quebec. DFO Gulf Region Fisheries and Aquaculture Management requested advice on reference points that conform to the Precautionary Approach (PA) to guide further management decisions for the developing Striped Bass fisheries. DFO management also requested a review of the approaches and potential reference points for Striped Bass that take account of interactions of Striped Bass and other species of fisheries value. For purposes of assessment and development of fisheries reference points, the southern Gulf Striped Bass population consists of the Gulf of St. Lawrence region extending to the north shore of the Gaspe Peninsula in Quebec (Figure 1).*

A science peer review meeting was conducted November 23-25, 2020 (virtually) in Moncton, New Brunswick. Participants (23 in total) at the science review were from DFO Science, DFO Fisheries and Aquaculture Management, the province of Quebec (Ministère des Forêts, de la Faune et des Parcs), the

State of Maine Department of Marine Resources, an Indigenous organization from PEI, and the COSEWIC co-chairs and report authors from academia.

SUMMARY

- Striped Bass (*Morone saxatilis*) of the southern Gulf of St. Lawrence (from western Cape Breton Island NS to the north shore of the Gaspe Peninsula QC) is considered to be a single biological unit for the purpose of this assessment and the derivation of reference points.
- This Striped Bass population has been annually assessed since 1994 and its life-history characteristics, including size-at-age, length-weight relationship, and sex ratio of spawners are well defined.
- An age structured population model with an underlying Beverton-Holt stock and recruitment relationship (from eggs to age-0) was used to model the population dynamics of Striped Bass. The model uses a combination of estimated and assumed life history parameters, most of which are specific to this population. Seven models were evaluated; the two preferred models are presented in this report.
- Monitoring and stock assessment data of the spawners in the Northwest Miramichi River, the annually predictable and confirmed spawning location that produces recruitment, are considered representative of Striped Bass in the southern Gulf and appropriate for deriving reference points.
- The near monotonic increasing trajectory of the population abundance from its low point in the late 1990s at less than 5,000 spawners to the highest abundance in the late 2010s of over 300 thousand spawners provides limited information to unequivocally define the maximum potential population size. A conclusion from the population modelling with the available data is that the maximum abundance of this population has not yet been realized.
- Reference values are defined in terms of eggs and converted to equivalent numbers of spawners to aid in interpretation.
- The number of eggs that equate to 80% Bmsy (80% of the spawning stock biomass that produces maximum sustainable yield) is proposed as the Upper Stock Reference (USR). There is no model consensus for the USR value. An Upper Stock Reference value of 54.3 billion eggs, equivalent to 720 thousand spawners, is the lowest value of two models retained (versus 1,2[1] million spawners for the other model).
- The number of eggs that result in half of Beverton-Holt carrying capacity is proposed as the Limit Reference Point (LRP). There is no model consensus for the LRP value; 17.3 billion or 30.0 billion eggs depending on the model, equivalent to 330 to 560 thousand spawners. Based on the trajectory of this population over the relatively short period of assessment, maintaining spawners above 330 thousand fish should be sufficient to avoid serious harm.
- The status is presented in terms of estimated eggs from spawners and perspectives on status are model dependent. The highest estimated spawner abundance of approximately one million fish in 2017 was approximately at the USR or in the cautious zone depending on

[1] Erratum: December 2022, corrected the value to correspond to the table in the body of the report

the model. Otherwise, the status was either below the LRP in all years except 2017, or below the LRP until 2015 and in the cautious zone since 2016.

- Fisheries management actions were responsive to the decline and rebuilding of the Striped Bass population, beginning with the closure of all directed fisheries for Striped Bass in 2000, followed twelve years later with the re-opening of the Indigenous FSC fisheries in 2012, and the retention recreational fisheries in 2013. This increased fisheries access occurred as the stock abundance was on an increasing trajectory of abundance, moving into the cautious zone.
- Prey of Striped Bass in May and June in the Miramichi River include Rainbow Smelt, gaspereau, occasionally Atlantic Salmon smolts, as well as several other fish and invertebrate species. Alternate reference levels to address the multiple species concerns related primarily to predation by Striped Bass on these prey species cannot be determined at this time based on the available information.
- The most important assessment and management uncertainty is the lack of comprehensive recreational fisheries catch and harvest data. In absence of such data, assessments of the dynamics and robustness of this population to fishing and environmental variation cannot be provided.

INTRODUCTION

Striped Bass (*Morone saxatilis* Walbaum, 1792) is widely distributed throughout the estuaries and coastal waters of the southern Gulf of St. Lawrence (southern Gulf), from the northern tip of Cape Breton Island (NS) in the east to the north shore of the Gaspe Peninsula (Quebec) in the west. The population in the southern Gulf of St. Lawrence is considered to be the most northern spawning population of the species distribution (Figure 1).

Genetic analyses and conventional tagging studies have indicated that this population is geographically isolated within the southern Gulf and estuary of the St. Lawrence. Striped Bass juveniles (age-0) originating from the Miramichi River were used in a re-introduction program in the St. Lawrence River beginning in the late 1990s. Successful spawning and recruitment from this program has been confirmed (DFO 2017; L'Italien et al. 2020). Tracking studies of acoustically-tagged Striped Bass from the St. Lawrence River group and from the southern Gulf of St. Lawrence group, as well as differences in elemental composition of the otoliths of bass spawned in the Miramichi River and in the St. Lawrence River, show a general geographic isolation of the two groups. The St. Lawrence progeny are generally restricted to the St. Lawrence River itself (at least to date), whereas the fish originating from the Miramichi have a broader distribution that extends into the estuary of the St. Lawrence and to the lower north shore of the St. Lawrence River (Valiquette et al. 2017, 2018). An extraordinary expansion of Striped Bass into previously undocumented areas along the lower north shore of the St. Lawrence River and into southern Labrador occurred in 2017 (DFO 2018; Valiquette et al. 2018) and the potential range of the southern Gulf Striped Bass population is now considered to occasionally extend into those northern areas.

The Striped Bass population of the southern Gulf of St. Lawrence had declined to less than 5,000 spawners in the late 1990s. Due to conservation concerns, the commercial fishery was closed in 1996, followed by the closure of the recreational fishery and the suspension of Indigenous Food, Social, and Ceremonial (FSC) fishery allocations for Striped Bass in 2000. The estimated abundance of Striped Bass spawners subsequently increased to over 200 thousand spawners in 2011, followed by a peak abundance estimated at over 900,000 spawners in 2017 (DFO 2018). Accordingly, Indigenous FSC fisheries were reinstated in 2012 and allocations of Striped Bass to indigenous groups have gradually increased since then. The recreational fishery reopened in 2013 with increasing annual access. A pilot Indigenous commercial fishery was conducted in 2018 to 2020.

In response to the trend of increasing abundance of Striped Bass and with requests for additional fisheries access to southern Gulf Striped Bass, Fisheries and Oceans Canada (DFO) Gulf Ecosystems and Fisheries Management Branch requested the development of reference points that conform to the Precautionary Approach (PA) to guide future management decisions for Striped Bass fisheries. DFO Fisheries Management also requested a review of approaches and potential reference points for Striped Bass that take account of interactions between Striped Bass and other species of fisheries value.

The specific objectives of the science peer review and advice provided in this report include:

- A review of the available information on the abundance and biological characteristics (size-at-age, mortality rate estimates, size structure) of the Striped Bass population of the southern Gulf of St. Lawrence relevant for the definition of reference points;
- A review of candidate fishery reference points for Striped Bass and estimates of these based on the available information from the southern Gulf population;
- A review of the consequences of fishery management measures on the derivation of fishery reference point values;
- Options for incorporating species interaction considerations in the definition of reference points for Striped Bass; and
- Consideration of the uncertainties in the definition of the reference points and management approaches for Striped Bass.

Species Biology and Distribution

General descriptions of Striped Bass biology and life history are available in COSEWIC (2012) and summary information for the southern Gulf population is available in Douglas et al. (2003).

- Striped Bass is a relatively long-lived iteroparous spawner. Maximum age estimated from otoliths along the eastern seaboard of the US is 31 years. In the southern Gulf population, maximum age from scale interpretations is 15 years and maximum fork length in sampling records is 116 cm, although there are incidental reports of catches of larger Striped Bass in this region.
- The Northwest Miramichi River estuary is the only confirmed spawning location that is annually predictable in time and space and that has produced annual recruitment in the southern Gulf of St. Lawrence. In the last few years, opportunistic sampling has confirmed the presence of Striped Bass eggs and larvae in the Southwest Miramichi and the Tabusintac River, both geographically proximate to the Northwest Miramichi however the extent to which the spawning in these areas contributes to recruitment to the southern Gulf population has yet to be determined.
- Spawning occurs in late May to early June in the upper estuary at the upper extent of the salt wedge within tidal waters of the Northwest Miramichi River and the eggs and milt are broadcast simultaneously into the water column. The eggs float freely, are generally neutrally buoyant in slightly saline water, and hatch after a few days depending on water temperature.

- The larvae feed on planktonic organisms and move to the near shore shallow areas of the rivers shortly after the onset of exogenous feeding.
- Young-of-the-year (YOY) Striped Bass gradually migrate downstream to Miramichi Bay in the summer and diffuse in a northwest and easterly direction from the Miramichi (Robinson et al. 2004) with a coastal distribution of young of the year by the first autumn extending at least from Miscou Island (NB) in the north to Pictou (NS) in the east (Douglas and Chaput 2011).
- Post-spawned adults return to marine waters and undertake coastal feeding migrations through the summer and autumn.
- Striped Bass is a generalist feeder with shifts in prey composition occurring with age and size. Larger bass are known piscivores, and consume a wide range of invertebrate and vertebrate prey, including a number of anadromous species of fisheries interest (Rainbow Smelt, gaspereau, Atlantic Salmon smolts).
- The southern Gulf of St. Lawrence population cannot tolerate sub-zero water temperatures and therefore seek water temperatures above zero in the upper areas of estuaries in the southern Gulf to overwinter.
- In its most recent assessment, COSEWIC assessed the status of the population as Special Concern (COSEWIC 2012). The Government of Canada decided not to add the Striped Bass population of the southern Gulf of St. Lawrence to Schedule 1 of the *Species at Risk Act* in March 2013.

Fisheries

Striped Bass has been exploited in numerous fisheries of the southern Gulf of St. Lawrence for over a century of records. Many regulatory changes have occurred in the Striped Bass fisheries that impact these fishing activities and recorded harvests. The most important changes occurred in the mid-1990s in response to concerns about low population abundances.

In 1996, an amendment to the Maritime Provinces Fisheries Regulations eliminated the authorization for the retention of Striped Bass bycatch in commercial fishing gears for gaspereau, Rainbow Smelt, American Shad, and American Eel, effectively closing the commercial fishery. By 2000, all legal Striped Bass fisheries, including recreational fisheries were closed and allocations in Indigenous Peoples FSC fisheries were suspended. Following on the rebuilding of the Striped Bass abundance in the late 2000s, Indigenous FSC fisheries allocations were reinstated in 2012, the recreational fishery was reopened in 2013, and a pilot Indigenous commercial fishery in the Miramichi River was licenced in 2018 to 2020. Striped Bass originating from the southern Gulf is also exploited in the recreational fisheries along the south and north shores of the Gaspe Peninsula, in fishing waters managed by the province of Quebec. Fisheries management measures for the recreational Striped Bass fishery in Quebec that, for the most part, paralleled the fisheries management measures in DFO Gulf Region were introduced in 2013.

In addition to a season, daily bag and possession limits, and gear restrictions, short-term closures to directed recreational fisheries lasting 5 to 9 days in the spawning area of the Northwest Miramichi have also been imposed since 2017 to preclude harm to spawning fish.

Fisheries catches and harvests

Complete fishery catch data for Striped Bass in the southern Gulf of St. Lawrence are lacking. Historically, fisheries statistics included only commercial harvests, exclusive of recreational and

Indigenous peoples fisheries harvests. First records of bass landings in fisheries date to 1868 but these data have not been compiled into a single report. The reported landings of Striped Bass from the southern Gulf of St. Lawrence for the period 1917 to 1988, compiled by LeBlanc and Chaput (1991), show a maximum catch for that time period of 61.4 t reported in 1917. There were no recorded landings for the years 1935 to 1967. Peak recorded landings in the second period of records after 1967 were 47.8 t in 1981 with 15.25 t recorded in the last year (1996) of authorized commercial landings (Douglas et al. 2006).

There are no compiled reports of catches and harvests of Striped Bass in the Indigenous FSC fisheries in the southern Gulf.

Since the re-opening of the recreational fisheries in 2013, partial catch data from the recreational fishery for some geographic areas of the southern Gulf and in some years have been collated but they are incomplete. There is no licence requirement to fish recreationally in tidal and marine waters, hence the number of anglers is unknown. The recreational fishery occurs from pleasure boats and from shore, in estuaries and along the coast, from wharves, public beaches, etc. along a broad geographic area and the potential number of anglers is very large.

ASSESSMENT

Monitoring and stock assessment data of the Striped Bass spawners in the Northwest Miramichi River, the annually predictable and confirmed spawning location that produces recruitment, for the period 1994 to 2019 are considered representative of Striped Bass in the southern Gulf and used in the modelling of population dynamics and in the derivation of reference points. The monitoring programs also provide information on biological characteristics of the southern Gulf Striped Bass population, including length-at-age, weight-at-age, maturity-at-age, and proportion female-at-age on the spawning grounds. The biological characteristics information is used in an age-structured, population model to estimate stock and recruitment parameters and associated age-specific mortality rates at age.

Using the biological characteristics and the parameter estimates from the population dynamics modelling, equilibrium modelling is then used to derive candidate Limit Reference Points (LRP), Upper Stock Reference (USR) levels, and removal rate references that would conform with the PA.

Abundance and Abundance-At-Age

Since 1994, monitoring of the bycatch in the commercial gaspereau trapnets of the Miramichi River has been the principal source of information for the estimation of the Striped Bass spawning population of the southern Gulf of St. Lawrence (DFO 2020). Estimated abundances of spawners in the Northwest Miramichi were at or under 5,000 spawners (median) during 1996 to 2000 (DFO 2020). Abundance increased to between 16,000 and 26,000 during 2001 to 2006 and again to between 50,000 and 100,000 fish during 2007 to 2010. Abundances of 150 thousand to 300 thousand were estimated during 2011 to 2016 with a peak abundance in 2017 at just under one million fish (Figure 2). Striped Bass spawner abundance in 2018 and 2019 was estimated to have fallen back to approximately 300 thousand spawners.

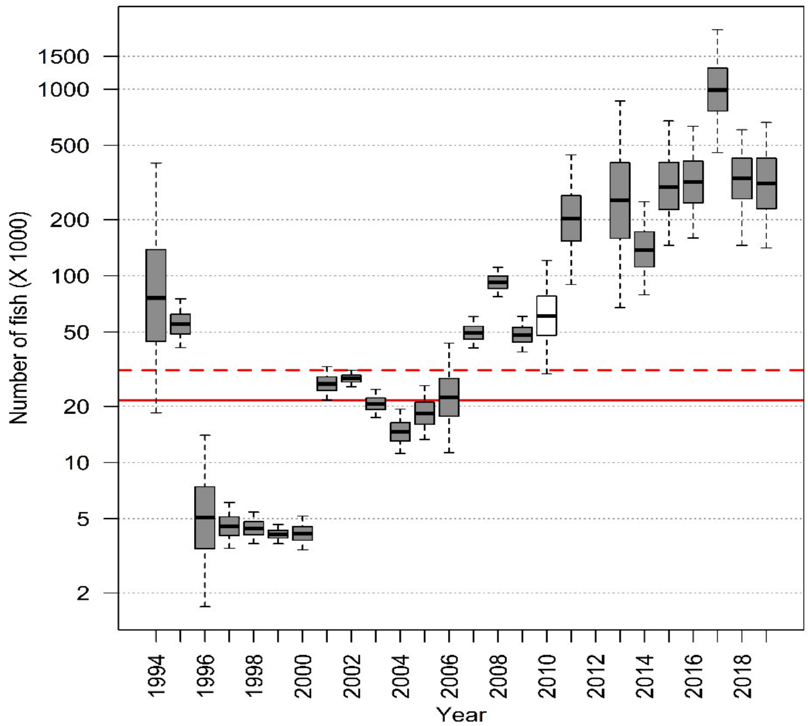

Figure 2. Estimated abundance of adult Striped Bass spawners in the Northwest Miramichi estuary between 1994 and 2019. The estimates are shown on a logarithmic scale for visibility of the full range of abundance values over the time series. The estimate for 2010 (unshaded interquartile box) is considered to be an underestimate due to the earlier timing of the spawning events (Douglas and Chaput 2011). There is no estimate for 2012 because spawning was very early and Striped Bass left the sampling area prior to monitoring activities (DFO 2013). Box plots are interpreted as follows: dash is the median, boxes are the interquartile range, and the vertical dashes are the 5th to 95th percentile ranges. The solid and dashed horizontal lines show the limit and target recovery objectives, respectively, defined in the Recovery Potential Assessment in support of the Species at Risk Act listing decision process (DFO 2006). The figure is reproduced from data in DFO (2020).

Scale samples from Striped Bass spawners sampled in May and June were interpreted for age and a von Bertalanffy growth model was used to characterize the fork length-at-age relationship. Scale sampling and age interpretations are not available for all assessment years, nor are there sufficient samples of older and larger fish in any year to adequately estimate their relative abundances. The predicted sizes-at-age (Table 1) from the growth model were used to derive an age-length key which was applied to the annual length distributions of the spawners to estimate the annual abundance-at-age of spawners.

A length-weight relationship, for sexes combined, was estimated using whole weight (kg) and fork length (cm) data obtained from sacrificed samples of spawners in the Northwest Miramichi River during May and June, 2013 to 2015. This relationship was used to derive mean weight-at-age values of spawners (Table 1).

There are no data with which to directly estimate the age or size at 50% maturity because no representative sampling of bass for age and maturation assessment is available. The maturation schedule of male and female bass was assumed to differ, with males first maturing at age 3 years and female bass first maturing at age 4 years, and all bass being mature by age 6 years (Table 1; Douglas et al. 2006). The assumed maturation schedule and the resulting proportion female at age of the spawners are supported by observations of the sex ratio at length from sacrificed samples of May and June in the Northwest Miramichi. There is a low proportion female for bass ranging from 33 to 48 cm, roughly equivalent to age 3, and an increasing proportion of females in the size range of age 4 bass with the proportion of females levelling off at around 0.5 for size ranges of bass aged 5 and older (Table 1).

There is no southern Gulf specific fecundity to weight relationship for Striped Bass. For modelling purposes, a value of 83,000 eggs per kg was used, based on estimates from other populations of Striped Bass.

Table 1. Biological characteristics by age of Striped Bass from the southern Gulf of St. Lawrence. These characteristics are used in the modelling of population dynamics and in the equilibrium modelling to derive reference points.

Age (years)	Predicted mean fork length (cm)	Predicted mean weight (kg)	Assumed proportion mature		Estimated proportion female at age of spawners
			Male	Female	
1	17.5	0.06	0	0	0
2	29.0	0.29	0	0	0
3	38.5	0.68	0.5	0.1	0.17
4	46.7	1.20	0.9	0.5	0.36
5	53.6	1.82	1.0	0.9	0.47
6	59.4	2.47	1.0	1.0	0.50
7	64.4	3.17	1.0	1.0	0.50
8	68.6	3.81	1.0	1.0	0.50
9	71.9	4.40	1.0	1.0	0.50
10	75.0	5.00	1.0	1.0	0.50
11	77.6	5.54	1.0	1.0	0.50
12	79.4	5.95	1.0	1.0	0.50
13	81.4	6.40	1.0	1.0	0.50
14	82.8	6.75	1.0	1.0	0.50
15	84.2	7.06	1.0	1.0	0.50

Mortality

Mortality-at-age is assumed to be similar for male and female Striped Bass.

Mortality-at-age is a parameter that is estimated in the population model. Inferences of mortality-at-age for the younger age groups (ages 0 to 3 years) cannot be made based on the data used in the model hence other methods are used to estimate it. Estimates of natural mortality (M) to be used as priors in the population modelling for age – 0 (overwinter survival), and ages 1 to 2 were derived using the empirical relationship published in Gislason et al. (2010) that relates instantaneous natural mortality rate to von Bertalanffy growth characteristics of the species (Table 2).

Acoustic tagging and tracking programs of Striped Bass conducted in 2003, 2004, 2008, 2009, and 2013 to 2017 provide independent data to estimate annual mortality (converse survival) rates of adult (age-4+) Striped Bass to the Miramichi River. Sequential detections of tagged bass from acoustic receivers in the Miramichi River are used. It was assumed that fish detected in the Miramichi one year would be expected to return to the Miramichi the following year, and the ratio of numbers of animals detected over the two periods provides an estimate of survival rate. These survival rate estimates would include both natural and fishing mortality because these fish would have been vulnerable to legal and illegal fisheries over those years. Estimates of instantaneous mortality rates (Z) were 0.41 (median; survival = 0.66) during the period 2003 to 2009 and Z = 0.22 (median; survival = 0.80) for the period 2014 to 2018 (Figure 3). It is not possible to partition the natural mortality rates from fishing mortality rates with these data however considering that fishery removals would have in part contributed to the estimated mortalities, natural mortality of adult sized (> 47 cm) Striped Bass should therefore be less than 0.2 (Figure 3).

Table 2. Predicted natural mortality (M) at age of Striped Bass based on the fitted von Bertalanffy growth characteristics and the empirical relationship of M to growth characteristics from Gislason et al. (2010).

Age	Mid-season mean size (mm) ($L_{a,t}$ to $L_{a+1,\ t+1}$)	Predicted M	Predicted survival ($S = exp^{-M}$)
0	135 (110 to 160)	1.97	0.14
1	232 (175 to 290)	0.82	0.44
2	337 (290 to 385)	0.45	0.64
3	426 (385 to 467	0.31	0.73

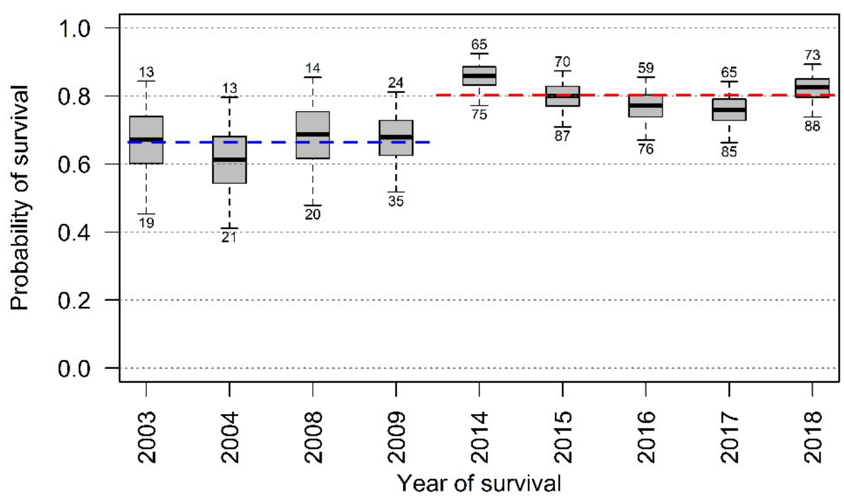

Figure 3. Posterior distributions of the estimated probabilities of survival (S) of acoustically tagged Striped Bass based on annual sequential detections in the Miramichi, pooled over size groups, tag types and release locations. The horizontal dashed lines represent the median annual survival probabilities for the 2003 to 2009 period and the 2014 to 2018 time period, respectively. The inferred year of survival represents the calendar year (e.g. 2017 is the survival over the period between winter 2016/17 and winter 2017/18). Boxplots show the 2.5 to 97.5 percentile ranges as whiskers, the interquartile range as the rectangle, and the median as the internal dash. The numbers shown in each panel for each boxplot are the numbers of fish detected (above) and the number of tags available (below) used in the estimation of the survival rates.

Population Modelling

An age structured population model with an underlying stock and recruitment relationship (from eggs to age-0 or to age-3 dependent on choice of model) was used to model the population dynamics of Striped Bass. The life cycle population dynamics incorporate the estimated and/or assumed life history characteristics of the Striped Bass population of the southern Gulf. Fork length-at-age, weight-at-age, and mortality-at-age are assumed to be similar for male and female Striped Bass. The beginning of the year is the spawning period, mid-May to mid-June, corresponding to the assessment period.

A series of age-structured life cycle models with differing assumptions and parameters to be estimated were examined (models 1 to 6). Some life history characteristics (mean weight-at-age, proportion female-at-age of spawners, eggs per kg of spawner) were set at fixed values in all model variants. For the other life history parameters (Beverton-Holt stock and recruitment parameters, mortality-at-age, proportion of recruits that are spawners), prior distributions were used. As there are no catch data for the Striped Bass fisheries of the southern Gulf that could be used in the population model, only total mortality (natural and fishing mortality) at age is estimated in the model. Time varying parameters were not considered in the models.

The time series of total abundance of spawners and estimated abundances at age for the period 1996 to 2019 were used (Figure 2). The data series begins in 1996 because prior to 1996, there was an active harvest of Striped Bass on the spawning grounds in the gaspereau fishery that was removing fish concurrent with the assessment program; the assessed population estimates for 1994 and 1995 are considered to be potential spawners rather than realized spawners. The same situation may apply since 2013 concurrent with the reopening of the Indigenous FSC fisheries and recreational fisheries, however, the harvest of Striped Bass during the assessment period (mid-May to mid-June) for those years is considered to be substantially less than what occurred prior to 1996.

Estimates of key life history and population dynamics parameters from the population model were used to derive Maximum Sustainable Yield (MSY) and other reference points. Estimates of natural mortality (M) at age of the age groups that are potentially exposed to directed fishing are required. Since the population model estimates total mortality (Z) these values are not used; rather information from acoustic tagging studies was used to define a reasonable value for natural mortality (M = 0.2) at ages 4 years and older. Model estimates of mortality-at-ages 0 to 3 were considered synonymous with natural mortality for those age groups.

Population modelling results

The time series of increasing abundance of spawners for the Striped Bass population during 1996 to 2019 follows a one way trajectory and the observations provide limited information to clearly define the population dynamics (Figure 2). Although, from a theoretical perspective, compensatory density dependence has been demonstrated to be necessary for population regulation (and hence surplus production to support a fishery) to occur, the data are insufficient to adequately characterize the strength of this relationship for this population. There is insufficient evidence to unequivocally conclude or reject the assumption of a density-dependent compensatory stock and recruitment relationship for this population. Model variants 1 to 3 were dismissed because of poor fits and models 4 to 6 are discussed below.

A priori, a density dependent Beverton-Holt stock and recruitment function with density dependence occurring between eggs and age 0 summer abundance is assumed (models 4 and 5). The spawning / nursery habitat and food base for the larvae and post-metamorphosis juveniles are constrained to a relatively small tidal area in the Northwest Miramichi, with the carrying capacity limit at the early juvenile (age – 0, summer) phase. Juveniles in their first summer gradually emigrate from the spawning area of the Northwest Miramichi and spread through other estuaries and coastal areas of the southern Gulf by their first autumn.

Model 6, with the stock and recruitment dynamics expressed from eggs to age 3, provided equally good fit to the observations compared to models that considered eggs to age 0 recruitment (models 4 and 5). However, the estimated carrying capacity at age 3 from model 6 is approximately nine times and four times higher than the scaled carrying capacity to age 3 for models 4 and model 5, respectively. Although, in-of-themselves, the data do not sufficiently preclude model 6, the limit reference points from this model are not consistent with the growth of this population. Specifically, the observation that the population has recovered rapidly from levels lower than the estimated limit reference points from Model 6 indicate that irreparable harm has not occurred at abundance levels lower than estimated LRP's from this model.

In terms of model diagnostics, the differences between model 4 and model 5 are small and insufficient to choose one model over the other (Table 3; Figure 4). Model 4 estimated survival rates at ages 0, 1, and 2 whereas model 5 estimated the cumulative survival from age 0 to 3. There were no observations of abundance at those age groups to objectively estimate those mortality rates.

All other parameters of the models including total mortality for ages 3 to 15+ and the proportion of recruits that become spawners had similar estimated values.

Table 3. Summary (median; 5th to 95th percentiles range) of posterior estimates of the stock and recruitment parameters and predicted abundances from models 4 and 5 with a Beverton-Holt stock and recruitment function from eggs to age-0. The equilibrium abundance estimates are based on the equilibrium model with life history parameters from the specific population model fits, assuming no fishing.

Population dynamics descriptor	Model 4 (BH-eggs to age-0)	Model 5 (BH-eggs to age-0)
Survival eggs to age 0 (α; slope at the origin)	5.34 E-4 (3.53 E-4 to 8.27 E-4)	2.28 E-4 (1.32 E-4 to 4.02 E-4)
Survival age 0 to 3	0.0631 (0.0449 to 0.0869)	0.163 (0.103 to 0.249)
Survival eggs to age 3 (in absence of density dependence)	3.34 E-5 (2.45 E-5 to 4.76 E-5)	3.65 E-5 (2.51 E-5 to 5.65 E-5)
Asymptotic abundance (K; Beverton-Holt model) Age 0 (millions)	9.10 (6.25 to 12.46)	6.80 (4.06 to 10.27)
Asymptotic abundance (K; Beverton-Holt model) Age 3 recruitment (thousands)	566 (383 to 834)	1,074 (640 to 1,799)
Equilibrium abundance from modelling Age 0 (millions)	7.37 (4.94 to 10.22)	5.23 (2.87 to 8.38)
Equilibrium abundance from modelling Age 3 recruitment (thousands)	456 (314 to 685)	824 (444 to 1,466)

Model 4 estimates a higher survival rate at the origin and a higher carrying capacity to age-0, however, the carrying capacity at age 3 is lower for model 4 compared to model 5 due to the lower cumulative survival from age 0 to age-3 inferred from Model 4 relative to Model 5. The lower carrying capacity at age 3 and the higher survival rate at the origin from Model 4 will in turn result in lower reference values for MSY and other reference points compared to Model 5 (Table 3; Figure 4).

For the reasons expressed above, models 4 and 5 are carried forward as the preferred models. Estimates of MSY and candidate reference values are presented for both models 4 and 5.

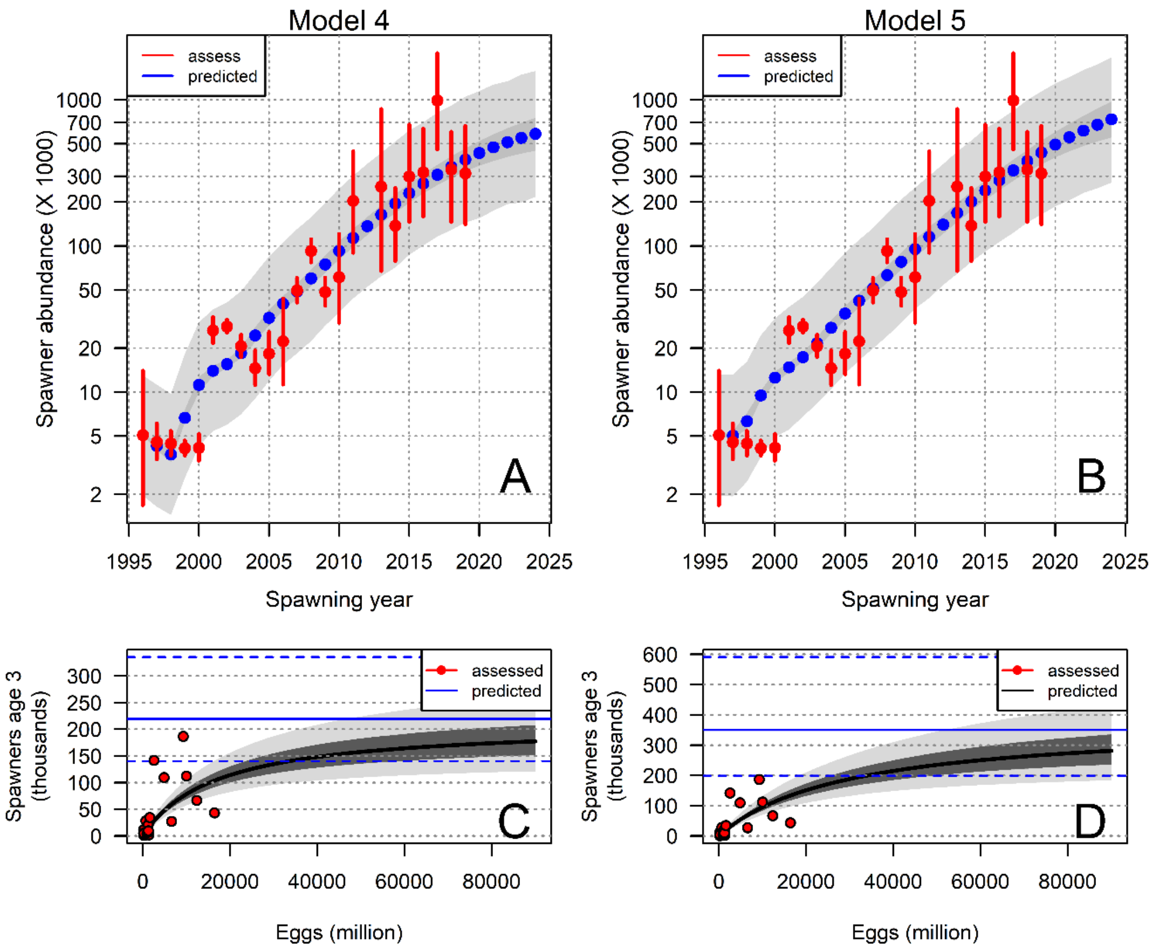

Figure 4. Observed and predicted total spawners of Striped Bass from the southern Gulf of St. Lawrence (upper row; A, B) and the stock and recruitment predicted abundance of spawners at age 3 years old (lower row; C, D) based on Model 4 (left panels A and C) and Model 5 (right panels B and D). In the upper row of panels, the assessed abundances are shown as red symbols for the median with 5th to 95th percentiles ranges as red vertical lines. The blue symbols are the predicted abundances, the darker grey shading is the 5th to 95th percentile range of mean predicted abundance and the light grey shading represents the 5th to 95th percentile range of the predicted spawner abundance accounting for the full process uncertainty. Note the y-axis abundance is shown on the log scale. In the lower panel, the assessed abundance of 3-year old spawners is shown as red symbols and the predicted median line with 25th to 75th and 5th to 95th percentile intervals are dark and light grey shading, respectively. The upper (blue) solid horizontal line (median) and the dashed horizontal lines (5th to 9th percentile range) are the Beverton-Holt asymptotic abundance (K).

Equilibrium Modelling to Define Reference Points

A forward projecting equilibrium approach, which simulates population abundance trajectories based on estimated and fixed life history parameters, is used to compare abundance, age structure, and fisheries yields at different levels of fishery exploitation as the population approaches its equilibrium abundance. The equilibrium model uses the same life cycle equations as in the estimation model with modifications to the catch equation to consider fisheries management strategies. Reference values based on MSY and spawner-potential-per-recruit (SPR) are examined with this model.

MSY is derived by searching over a range of fully-recruited fishing mortality rate (F) for the fishing rate (Fmsy) that results in maximum yield (in weight). Biomass at MSY (Bmsy), spawner abundance (number of fish) at Bmsy, catch (Cmsy; in number and weight), and age structure of the catch and of the spawners at MSY are extracted from the simulation outcomes.

SPR is presented as the percentage of the spawner potential (in terms of biomass or egg production) produced by an individual recruit throughout its life; this contribution decreases with increasing fishing mortality. SPR is presented as a percentage of the spawning potential which remains after fishing relative to a population that is not fished.

Estimates of natural mortality (M) at age are required for equilibrium modelling. For ages 0 to 3, the estimates of total mortality, as equivalent to natural mortality, from the population models are used because these age groups are not considered to be exploited in directed fisheries. For ages 4 years and older, the population model estimates are for total mortality (Z). Inferences on the maximum level of natural mortality expected for the southern Gulf of St. Lawrence population were obtained from the analysis of survival rates of acoustically tagged Striped Bass. For purposes of equilibrium modelling and to define reference points, comparisons of two assumptions for M were considered:

- Assuming M = Z, based on mortality rates derived from the population model for ages 3 to 15+;
- M at age 3 based on Z estimates from the population model and M = 0.20 for ages 4 to 15+ inferred from acoustic tagging information.

MSY and SPR reference points are context specific. The reference point values depend not only on the parameter estimates of the population dynamics (survival, proportion recruits to spawners) but also on the fisheries management scenarios, particularly those that have size restrictions for harvest retentions The size limits, combined with the size distributions at age, define the partial recruitment at age to the fishery and hence the proportion of the total annual losses at age attributed to fishing.

Management strategies based on size limits are examined with the model with respect to how these modify derived reference points (Table 4). Fishery selectivity at age (s_a) to fully-recruited F is determined using the predicted fork length distribution at age from the von Bertalanffy model relative to a defined management strategy based on fork length.

Table 4. Example management strategies based on size limits that were examined in the context of defining fishery reference points for Striped Bass.

Retention regulations	Minimum size (fork length, cm)	Maximum size (fork length, cm)	Comment
No size limits	na (30)	na (150)	For purposes of modelling, a minimum size of 30 cm was assumed as the smallest fish that would be retained. A maximum size of 150 cm was set that exceeds the expected size of any fish.
Slot size	47	61	As per recreational fisheries plan of 2016 to 2020.
Maximum size only	na (30)	65	For purposes of modelling, a minimum size of 30 cm was assumed as the smallest fish that would be retained.

MSY and SPR reference values

MSY and SPR reference values derived from equilibrium modelling are dependent upon the assumptions of natural mortality (Table 5). As expected, equilibrium abundances, abundance at Bmsy, and potential realized catch at Fmsy are higher when natural mortality is assumed to be lower for ages 4 to 15+ (Table 5, right column). In contrast, Fmsy (minimally) and fishing rates at 50% SPR and 30% SPR are higher when natural mortality is higher.

Table 5. MSY and SPR reference levels (median; 5th to 95th percentile range) derived from the equilibrium modelling based on life history parameters and population dynamics parameters from model 5 for the two scenario values of M. The results are specific to the management strategy without any size limit for retention and no accounting for catch and release mortality.

Reference values from Model 5	M = Z from modelling	M informed from acoustic tagging
Equilibrium abundance ages 3 to 15+ at F = 0		
Equilibrium total biomass (biomass, t)	4,140 (2,120 to 11,450)	13,980 (8,040 to 24,710)
Equilibrium total abundance (number, thousands)	2,320 (1,380 to 4,340)	4,700 (2,800 to 8,060)
Equilibrium spawners (biomass, t)	2,810 (1,430 to 8,100)	10,340 (5,400 to 19,410)
Equilibrium spawners (number, thousands)	1,360 (800 to 2,620)	3,110 (1,760 to 5,610)
Equilibrium spawners (eggs, millions)	104,300 (51,300 to 317,300)	413,900 (214,100 to 783,600)
MSY references (ages 3 to 15+) at F = Fmsy		
Equilibrium total abundance (biomass; t)	1,620 (890 to 3,600)	4,610 (2,680 to 8,000)
Equilibrium total abundance (number, thousands)	1,230 (740 to 2,230)	2,430 (1,460 to 4,130)
Equilibrium spawners (biomass, t)	1,010 (550 to 2,350)	3,200 (1,770 to 5,830)
Equilibrium spawners (number, thousands)	660 (390 to 1,240)	1,450 (850 to 2,550)
Equilibrium spawners (eggs, millions)	34,560 (18,190 to 85,230)	121,680 (65,990 to 224,330)
Fishing rate and yield at msy		
Fmsy (fully recruited F)	0.18 (0.12 to 0.23)	0.17 (0.15 to 0.19)
Catch at msy (biomass, t)	210 (130 to 380)	650 (370 to 1140)
Catch at msy (number, thousands)	160 (100 to 270)	340 (190 to 590)
SPR fully recruited F (ages 3 to 15+)		
F at 50%SPR	0.19 (0.14 to 0.27)	0.12 (0.11 to 0.13)
F at 30%SPR	0.39 (0.28 to 0.53)	0.24 (0.22 to 0.27)

Of the two retained models (4 and 5) with the stock and recruitment dynamic modelled from eggs to age 0, the MSY and SPR reference values are higher for Model 5 compared to Model 4 (Figure 5). Based on M for ages 4+ inferred from acoustic tagging observations, Bmsy from Model 5 is approximately twice as high as that from Model 4. Fmsy estimates of F = 0.17 are similar between models resulting in higher catch at msy (Cmsy) values, by a factor of two, from Model 5 compared to Model 4 (Figure 5).

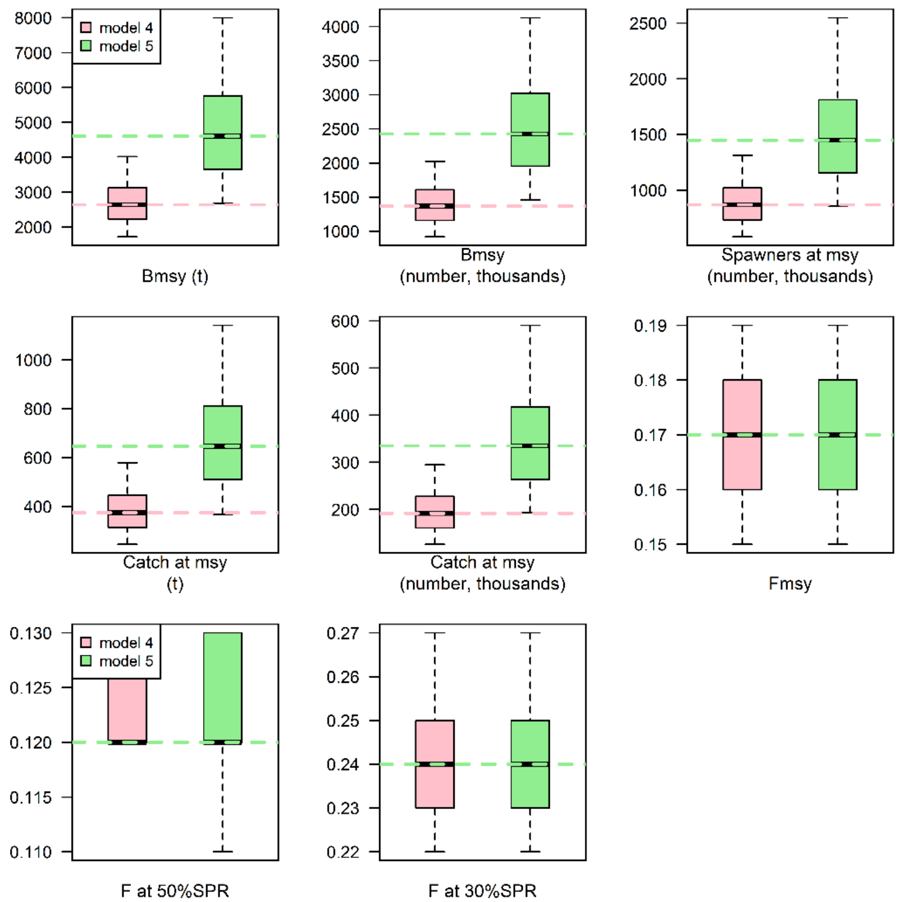

Figure 5. Comparison of MSY and SPR reference levels from Model 4 and Model 5 for scenarios with M informed by observations and for the default fishing strategy with no size limit and excluding catch and release mortality. The boxplot summaries are interpreted as follows: vertical dashed lines encompass the 5th to 95th percentile range, the boxes encompass the interquartile range, and the internal dash and dashed horizontal lines are the medians.

Fishing strategies (Table 4) have consequences on the MSY references when these are expressed in terms of numbers of fish because fishing changes the age structure of the population relative to the unfished condition (Table 6). A fishing strategy that maximizes yield in weight differs from one that maximizes yield in number. However, the consequences of fishing strategy on reference point values are small relative to the differences resulting from uncertainties in the underlying population dynamics (model 4 versus model 5).

Table 6. Comparison of estimated MSY reference values for different fishing strategies conditioned by size limits. The equilibrium simulations were run based on life history characteristics from Model 5 and assuming M for ages 4 to 15+ based on acoustic tagging observations. There is no accounting for catch and release mortality in these scenarios. Summary statistics shown are the median with the 5th to 95th percentile range. The results are similar for Model 4, in terms of direction of effects.

Reference values for Model 5	No size restrictions (slot = 30 to 150)	Slot size (47 to 61 cm FL)	Maximum size limit (30 to 65 cm FL)
Total abundance (biomass, t)	4,610 (2,680 to 8,000)	3,720 (2,210 to 6,450)	3,800 (2,250 to 6,630)
Total abundance (number, thousands)	2,430 (1,460 to 4,130)	2,060 (1,250 to 3,520)	1,990 (1,200 to 3,390)
Spawners (biomass, t)	3,200 (1,770 to 5,830)	2,550 (1,460 to 4,540)	2,610 (1,480 to 4,700)
Spawners (number, thousands)	1,450 (850 to 2,550)	1,180 (720 to 2,040)	1,140 (690 to 1,970)
Catch at msy (weight, t)	650 (370 to 1,140)	530 (300 to 940)	490 (280 to 850)
Catch at msy (number, thousands)	340 (190 to 590)	360 (210 to 640)	400 (230 to 700)

Candidate Reference Points

Striped Bass is a species of Indigenous FSC, recreational, and commercial fisheries value. Accordingly, the candidate reference points examined are based on concepts of MSY and spawner abundances to maintain a defined level of recruitment. A number of candidate reference points, based on those discussed in literature and policy (Mace 1994; DFO 2009) were examined.

Fishing strategies may have consequences on reference points because fishing changes the age structure of the population relative to the unfished condition. For purposes of defining values for the reference points, a fishing strategy that has no size restrictions for retention and that excluded catch and release mortality is used.

Reference points are presented in units of total eggs, as well as equivalences in number and biomass of spawners. Spawners are the component of the overall population of Striped Bass aged 3 years and older that are on the spawning grounds of the Northwest Miramichi at the time of the assessment during May and early June. This abundance is less than the total population of Striped Bass of those ages, as some of these are not mature while others are not on the spawning grounds during the period of monitoring and assessment.

Upper Stock Reference

Under DFO’s PA policy, the USR point defines the boundary between the Cautious and the Healthy zones. The USR is the stock level threshold below which removals must be progressively reduced in order to avoid reaching the LRP and must be set at an appropriate distance above the LRP to provide sufficient opportunity for the management system to recognize a declining stock status and sufficient time for management actions to have effect. The USR is determined by productivity objectives for the stock, broader biological considerations, and social and economic objectives for the fishery (DFO 2009). An Upper Stock Reference point that differs with fishing strategy is consistent with policy of the PA as the Upper Stock Reference can reflect socio-economic considerations.

Candidate upper stock reference points examined include:

- Eggs (spawner abundance) at 80% Bmsy and

- Eggs (spawner abundance) at equilibrium when the stock is fished at F corresponding to 50% of the SPR.

Of these candidates, the eggs (spawner abundance) at 80% Bmsy is preferred to avoid the arbitrary selection of the appropriate level of SPR (here 50%) (Table 7).

Table 7. Upper Stock Reference points for Striped Bass of the southern Gulf of St. Lawrence based on population dynamics parameters of two models, assuming M from acoustic tagging observations. Summary statistics shown are the median with the 5th to 95th percentile range.

Upper Stock Reference (80%Bmsy)	Model 4	Model 5
Eggs (millions)	54,300 (33,700 to 86,400)	91,320 (49,990 to 168,040)
Spawner biomass (t)	1,460 (920 to 2,290)	2450 (1360 à 4450)[2]
Spawner number (thousands)	720 (480 to 1,090)	1210 (710 à 2110)[2]
Eggs per spawner	75,400 (65,600 to 85,000)	75,670 (64,820 to 86,000)
Mean age of spawners	5.28 (4.94 to 5.61)	5.28 (4.91 to 5.64)

Limit Reference Point (LRP)

Under DFO's PA policy, the LRP defines the boundary between the Critical and the Cautious zones. The LRP represents the stock status below which serious harm is occurring to the stock. At this stock status level, there may also be resultant impacts to the ecosystem, associated species and a long-term loss of fishing opportunities. Candidate limit reference points examined include:

- Lowest abundance (eggs) that resulted in rebuilding of the stock (Brecover);
- Abundance (eggs) corresponding to 40% Bmsy;
- Eggs (or spawner number, spawner biomass) for half saturation (50% of Beverton-Holt K); and
- Eggs (or spawner number, spawner biomass) that result in 50% of recruitment at the unfished equilibrium population size based on Beverton-Holt stock and recruitment relationship and life history characteristics.

These options differ in their underlying assumptions and behaviour. Based on the PA policy (DFO 2009), the LRP should be determined by biological considerations and as such invariant to fisheries exploitation strategies. The 40% Bmsy reference point is not invariant, however, Brecover (although not entirely, based on fishing strategies of the past) and eggs for half saturation, or half equilibrium abundance are such points).

Brecover is not considered to be an appropriate LRP for this Striped Bass population. The lowest abundance that resulted in the rebuilding of the stock provides context about how the population has responded in the past. The lowest historical spawner abundance that did not prevent rebuilding of the population is equal to the low abundances during 1996 to 2000 with a

[2] Erratum: December 2022, corrected a transcription error from the model outputs

mean value of 4,300 fish spawners. There was a near monotonic increase from these low abundances to over 300 thousand spawners in less than 20 years. Estimated equilibrium abundance of ages 3 to 15+ in the absence of fishing is projected to be 3 to 5 million fish, 2 to 3 million spawners, dependent on the model. A Brecover value of 4,500 fish represents only 0.1% to 0.2% of the projected unfished abundance (synonymous with B0), and substantially less than a commonly discussed threshold biomass value of 20% B0.

Total eggs for half saturation or for half equilibrium abundance can be invariant to fisheries management strategy if the recruitment stage being maximized is not subject to fishing mortality and if the spawning stock is expressed in terms of eggs. The eggs for half saturation is based on the capacity of the habitat (environment) to produce recruits and does not depend on life history parameter values (e.g. natural mortality rates, age-at-maturity) for age classes older that the age at recruitment (age 3). As such, if the cumulative effects of natural and fishing mortality reduce abundance to the LRP, there is a “hard stop” and human-induced mortality is reduced to the lowest possible level. In contrast, the abundance (eggs) corresponding to 40% Bmsy and the eggs that result in 50% of the equilibrium abundance are both dependent on the life history parameter values for older fish. As such, if the natural mortality increases, both the equilibrium and the LRP would both decrease to lower and lower levels as natural mortality increases.

The eggs that result in half carrying capacity is proposed as the LRP (Table 8). Equivalent values in terms of biomass and number of fish are provided; the conversion from eggs to biomass or number of fish accounts for the changes in age structure of the population resulting from fishing. Overall, fishing has the effect of reducing the average age and average weight of the spawners resulting in a reduction in the population level eggs per spawner.

Table 8. Limit Reference Points for Striped Bass of the southern Gulf of St. Lawrence based on population dynamics parameters of two models. Summary statistics shown are the median with the 5th to 95th percentile range.

Limit Reference Point	Units	Model 4	Model 5
Brecover	Eggs (millions)	200	
	Spawners (biomass, t)	6.5	
	Spawners (number, thousands	4.5	
40%Bmsy	Eggs (millions)	24,500 (15,400 to 38,500)	40,580 (22,430 to 74,480)
	Spawners (biomass, t)	700 (450 to 1,080)	1160 (650 à 2090)[3]
	Spawners (number, thousands)	420 (280 to 630)	700 (410 to 1220)[3]
	Eggs per spawner	58,000 (50,700 to 65,200)	58,030 (50,080 to 65,850)
	Mean age of spawners	4.65 (4.41 to 4.90)	4.66 (4.39 to 4.92)
Half saturation Bev Holt	Eggs (millions)	17,300 (11,300 to 26,500)	29,950 (17,450 to 54,180)
	Spawners (biomass, t)	510 (340 to 760)	870 (520 to 1,560)
	Spawners (number, thousands	330 (220 to 490)	560 (350 to 980)

[3] Erratum: December 2022, corrected a transcription error from the model outputs

Limit Reference Point	Units	Model 4	Model 5
	Eggs per spawner	52,400 (46,400 to 59,100)	53,250 (46,240 to 60,640)
	Mean age of spawners	4.46 (4.26 to 4.69)	4.49 (4.25 to 4.74)
Half equilibrium abundance	Eggs (millions)	15,200 (10,000 to 23,000)	26,160 (15,420 to 47,040)
	Spawners (biomass, t)	450 (300 to 670)	770 (460 to 1,360)
	Spawners (number, thousands)	300 (210 to 440)	510 (310 to 880)
	Eggs per spawner	50,800 (44,900 to 57,200)	51,470 (44,590 to 58,450)
	Mean age of spawners	4.41 (4.21 to 4.62)	4.43 (4.20 to 4.67)

Fishing Removal Rate

The fishing rate reference points considered are:

- Fmsy;
- F corresponding to 30% SPR as a maximum fishing rate; and
- F corresponding to 50% SPR as a target fishing rate.

Fmsy is proposed as the removal rate reference (Table 9). Fmsy values when presented as fully-recruited F values are dependent on the fisheries management strategy. For clarity, the Fmsy values are also presented in terms of exploitation rate, expressed as the ratio of catch (number) to total abundance of fish ages 3 to 15+. The lowest overall exploitation rate is realized for a fishing strategy without size limits. Exploitation rates at Fmsy for three fishing strategies examined are at or less than assumed natural mortality rate of M = 0.2 (S = 0.82).

Table 9. Removal rate reference for Striped Bass of the southern Gulf of St. Lawrence based on population dynamics parameters of two models. Summary statistics shown are the median with the 5th to 95th percentile range.

Removal rate reference	Model 4	Model 5
Fmsy (fully recruited fishing rate)	0.17 (0.15 to 0.19)	0.17 (0.15 to 0.19)
Exploitation rate	0.14 (0.13 to 0.16)	0.14 (0.12 to 0.16)

Stock Status Perspective Based on Reference Points

The stock status relative to these model derived reference points, over the period of assessment 1994 to 2019 is shown in Figure 6. The status is presented in terms of estimated eggs, on the same unit as the reference points. Perspectives on status are model dependent. The estimated spawner abundance has been approximately at the USR only once (in 2017) based on Model 4 whereas the abundance in 2017 was in the cautious zone based on Model 5. Dependent on the model, the spawner abundances were either below the LRP in all years except 2017 (model 5) or below the LRP until 2015 and in the cautious zone since 2016 (Model 4) (Figure 6).

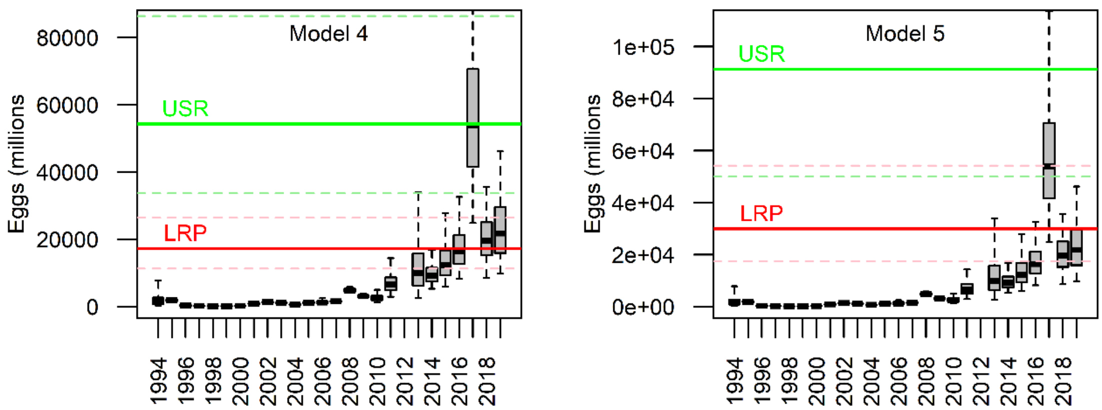

Figure 6. Assessed abundance of eggs in spawners (boxplots; eggs in millions) and status relative to the USR (upper green horizontal line) and the LRP (lower red horizontal line) candidate references from Model 4 (left panel) and Model 5 (right panel) for Striped Bass from the southern Gulf of St. Lawrence, 1994 to 2019. For Model 4 and Model 5, the USR corresponds to the median estimate of eggs at 80% Bmsy and the LRP corresponds to the median estimate of eggs that result in 50% of Beverton-Holt K (half saturation). The dashed red lines and green lines are the 5th to 95th percentile ranges of the LRP and USR respectively. Note the 95th percentile line of the USR and the 95th percentile point of eggs in 2017 are off scale in both panels.

Multi-Species Interactions

The policy to support rebuilding plans under the PA framework for stocks that are in the critical zone indicates that rebuilding objectives of a fish stock that has the potential to negatively impact the status of another species or stock (by example, rebuilding a predator species results in decline of a prey species) need to consider a balanced approach to ensure neither is depleted to a point of serious harm (DFO 2019). It is also indicated that it is not possible to simultaneously achieve yields corresponding to MSY predicted from single-species assessments for a system of multiple, interacting species (DFO 2019).

The reference points discussed in the previous section are based on single species management approaches for the purpose of maximizing yield and avoiding serious harm specific to Striped Bass. Modifying the single species reference points to account for interactions requires evidence of cause and effect consequences of Striped Bass on other species.

Striped Bass is a large bodied and generalist feeder on a variety of fish and invertebrates, with prey composition dependent upon the predator size (larger bass eat more fish), the time of year, and the foraging habitat. Striped Bass can switch among prey types based on availability and there are ample opportunities for Striped Bass to feed on diadromous species when these fish are migrating into rivers to spawn or out of rivers post-spawning and to feeding areas at sea.

Concerns have been expressed by several fisheries users that the rebuilding of the Striped Bass population in the southern Gulf has contributed to declines in abundances and their catches of Atlantic Salmon (*Salmo salar*), gaspereau (*Alosa pseudoharengus, A. aestivalis*), Rainbow Smelt (*Osmerus mordax*) and other species. The interaction is by Striped Bass predation on these potential prey species. The body sizes of gaspereau and Rainbow Smelt adult spawners and juveniles, as well as the body size of seaward migrating Atlantic Salmon smolts, are within the range of prey size for adult Striped Bass.

Gaspereau and Rainbow Smelt are important (occurrence) prey identified in Striped Bass stomachs sampled in May and June in the Miramichi River (DFO 2016). Recorded commercial landings of gaspereau and Rainbow Smelt from the NB districts of DFO Gulf Region for the period 1990 to 2018 show a steep decline beginning in 2005 (Figure 7). Commercial fisheries landings are generally not proportional to abundance, unless the proportion harvested is the same over time, which is almost never the case. The annual variations and declines in the landings are also likely due to factors such as changes in effort, changes in the number of active licences, and some differences in sales to buyers versus local sales (for bait) over time.

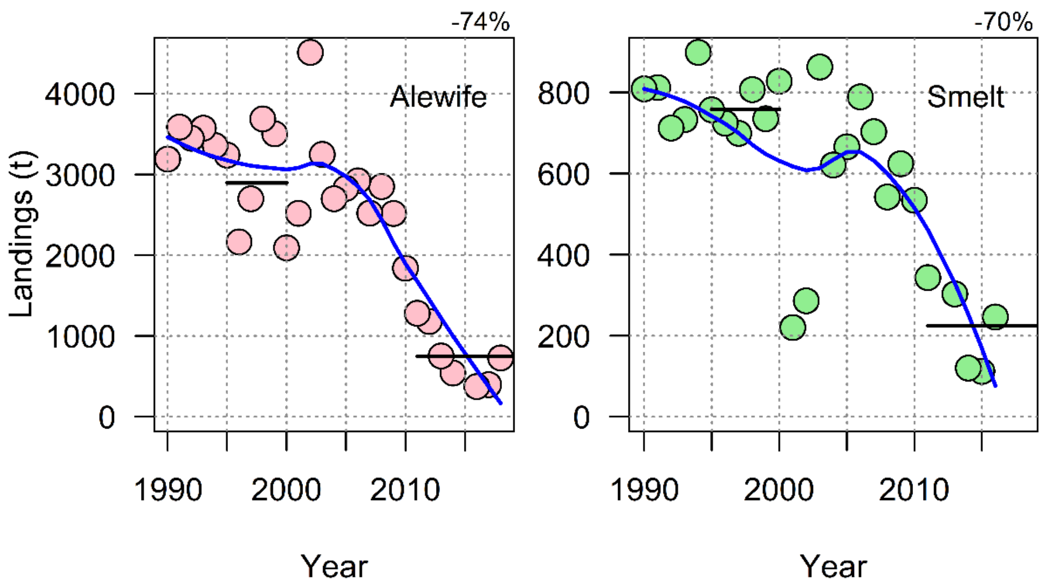

Figure 7. Recorded landings (t) of gaspereau (left panel; includes Alewife and Blueback Herring) and Rainbow Smelt (right panel) from the province of NB districts in DFO Gulf Region, 1990 to 2018. Some data are missing due to confidentiality restrictions. The blue line in each plot is a LOESS smoother using a span value of 0.8. The mean landings for the periods 1995 to 2000 and 2011 to 2018 are shown as black horizontal lines and the percent change of the 2011 to 2018 period relative to the 1995 to 2000 period is shown in the top right above each panel.

Fishery independent indices of abundance, based on total annual catches of four diadromous species, are also available from index estuary trapnets operated by DFO Science in the Northwest Miramichi (since 1998) and the Southwest Miramichi (since 1994) rivers (Figure 8). The index trapnets have been installed at the same location and monitored using similar procedures and protocols over the entire time series of operation.

Gaspereau and Atlantic Salmon indices declined at the facilities in both rivers, with the most important decline in the gaspereau index of the Southwest Miramichi (Figure 8). Collectively, causal Striped Bass predation and commercial fisheries would be expected to be most important in the Northwest Miramichi, however the decline in gaspereau indices was more important in the Southwest Miramichi.

Large increases in Striped Bass were noted in the catches in both the Northwest Miramichi and Southwest Miramichi; large increases in the Northwest Miramichi would be expected given the large increase in the population size of stock that spawns in the Northwest Miramichi. The abundance indices of American Shad (*Alosa sapidissima*) have increased at both facilities, with a larger increase in the Southwest Miramichi in which there is a recognized shad spawning area (Figure 8).

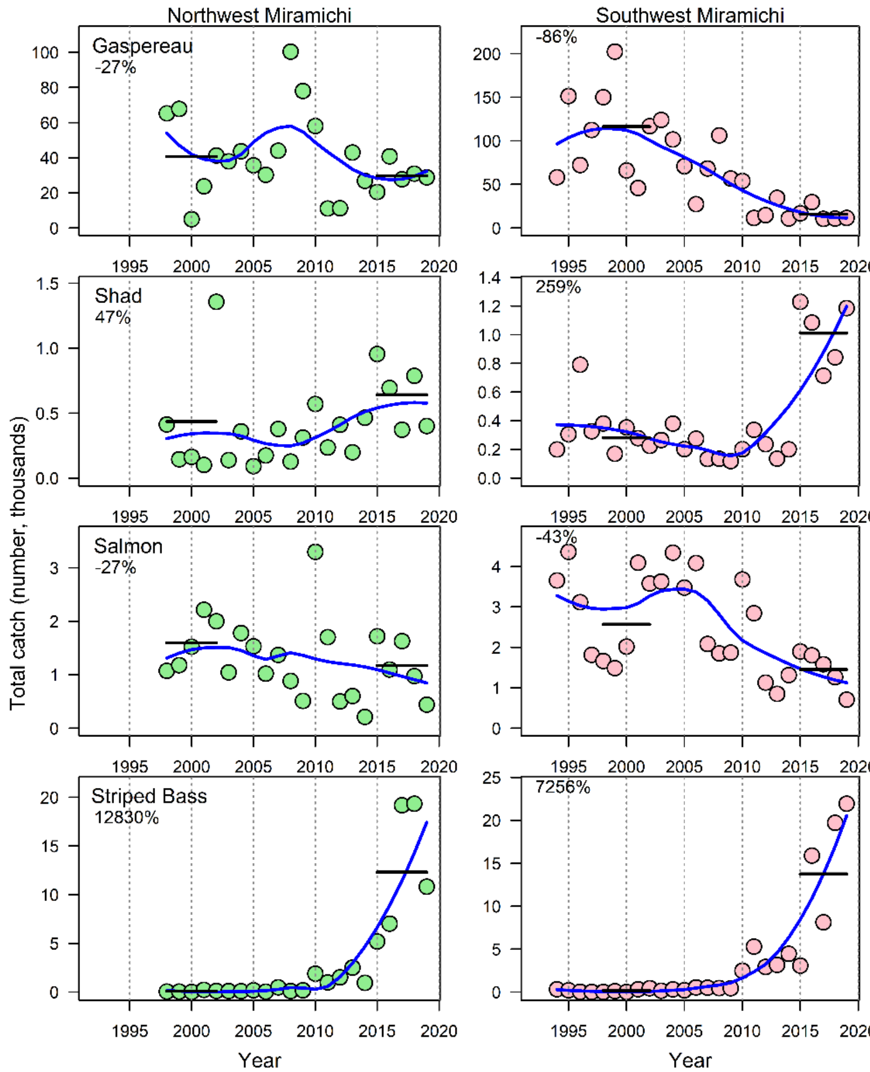

Figure 8. Summary of total catches (number, thousands) of diadromous fish species (Gaspereau = Alosa pseudoharengus and A. aestiavalis, top row; Shad = A. sapidissima, second row; Salmon = Salmo salar (adults), third row; Striped Bass = Morone saxatilis, fourth row) at the DFO index estuary trapnets in the Northwest Miramichi (left column) and the Southwest Miramichi (right column), 1994 (1998 for Northwest Miramichi) to 2019. Total catches are not corrected for dates of operation which can vary between years and between trapnets. The blue line in each plot is a loess smoother using a span value of 0.8. The mean catches for the periods 1998 to 2012 and 2015 to 2019 are shown as black horizontal lines and the percent change of the 2015 to 2019 period relative to the 1998 to 2002 period is shown in the top left corner of each panel.

Atlantic Salmon specific interactions

The most likely interaction between Atlantic Salmon and Striped Bass is expected during the seaward outmigration phase of Atlantic Salmon smolts. Atlantic Salmon smolts are of suitable body size range for most adult Striped Bass and the smolt migration timing and corridor from freshwater to the sea has smolts from the Northwest Miramichi River in particular migrating through the spawning area and the staging areas of Striped Bass at approximately the same time as Striped Bass are aggregating and spawning in the Northwest Miramichi.

There are direct observations of predation by Striped Bass on smolts based on stomach samples collected in May and June in the Miramichi River (DFO 2016). Indirect evidence of predation is provided from several studies using acoustic tags placed in Atlantic Salmon smolts with inferences of predation events based on movement patterns (Daniels et al. 2018), changes in identification codes of tags signaling a predation event (Daniels et al. 2019), and from changes in estimated survival rates in the early phase of migration through Miramichi Bay (Chaput et al. 2018).

A long term acoustic tagging and tracking study, conducted by the Atlantic Salmon Federation (ASF) since 2003 in four rivers in the southern Gulf of St. Lawrence, estimated that survival rates of “tagged smolts” through Chaleur Bay (Restigouche, Cascapedia rivers) were relatively high (67% to 95%), and with no change over time in contrast to the survival rates of “tagged smolts” through Miramichi Bay which were lower (28% to 82%) and showed a decline in survival beginning in 2010 (Chaput et al. 2018). The differences in apparent survival rates in two neighbouring coastal embayments have been hypothesized to be in part related to differences in predation pressure on migrating smolts from Striped Bass present in the Miramichi Bay during the smolt migration period but not in Chaleur Bay.

There is a negative relationship between Striped Bass abundance estimates and the estimated survival rates of acoustically tagged smolts (Figure 9). In both rivers, the lowest survival rates from head of tide to bay exit were estimated in the recent period (2013 to 2016) when the estimated abundance of Striped Bass was greater than 100 thousand spawners.

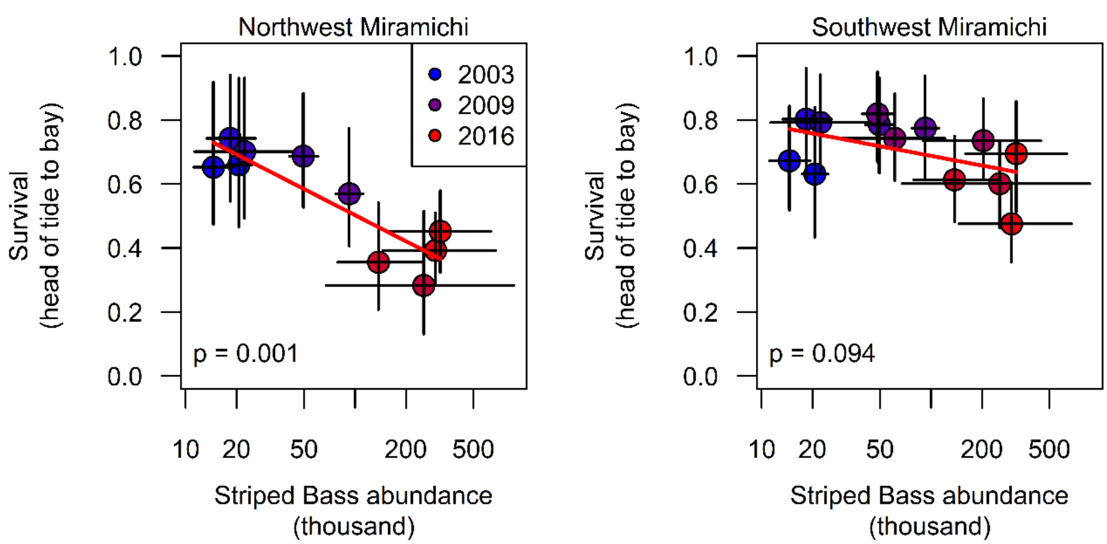

Figure 9. Association between the estimated survival rates from head of tide to bay exit of acoustically tagged smolts (Northwest Miramichi left panel, Southwest Miramichi right panel; data from Chaput et al. 2018) and the estimated spawner abundance of Striped Bass (log scale) in the Miramichi River, 2003 to 2016. For both the survival rates and spawner abundance values, the symbol is the median and the black lines are the respective 5th to 95th percentile range of the estimates. The linear relationship (red line) and the corresponding p-value of the slope of the regression = 0 is shown in the lower left corner of each panel.

Population level effects of predation by Striped Bass on Atlantic Salmon smolts were examined using annual indices of juvenile salmon abundance and the estimated returns of one-sea-winter and two-sea-winter first time spawning (maiden) salmon adults. Estimated relative survival rates in the first year at sea for the smolt migration years 1994 to 2018 show wide variation for both the Southwest and Northwest Miramichi river returns (Figure 10). Plotted against corresponding Striped Bass spawner abundances for the year of smolt migration (and the year of potential predation by bass), there is an apparent decline in relative survival rates of smolts from the Southwest Miramichi, especially for the 2006 to 2018 migration years (the highest relative survival rates were estimated for the 2009 smolt migration year) associated with increasing Striped Bass abundance (Figure 10). However, low relative survival rates for the Southwest Miramichi were estimated in the late 1990s when Striped Bass abundances were low. The relationship between relative survival rates and Striped Bass spawner abundances is not statistically significant for the Northwest Miramichi smolts (Figure 10).

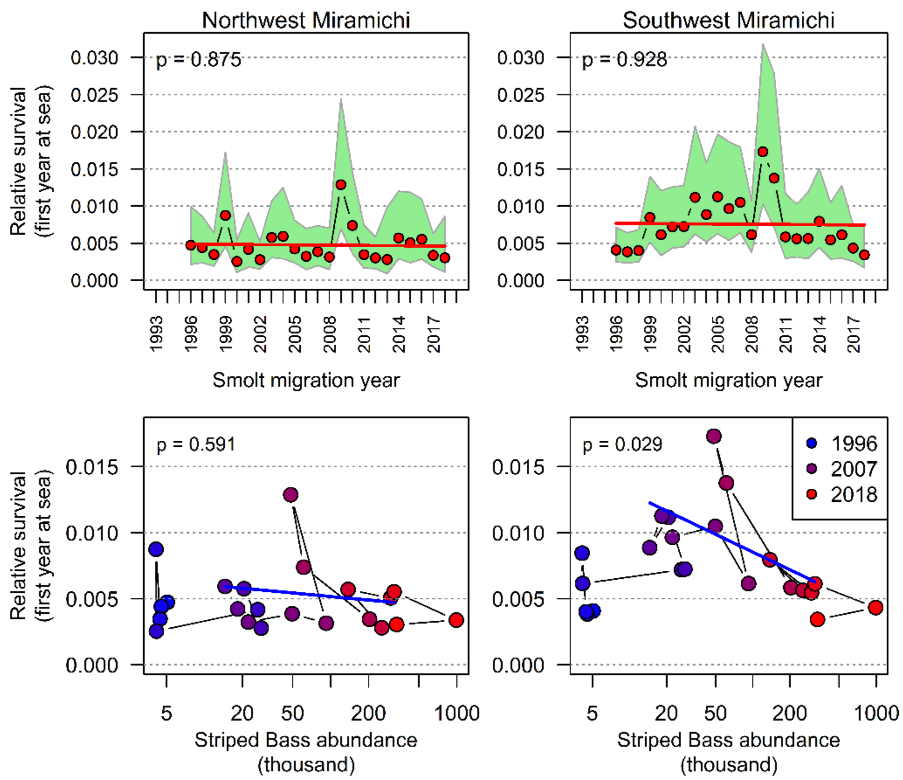

Figure 10. Posterior distributions of the relative survival rates during the first year at sea for smolts migrating from the Northwest (left column) and the Southwest (right column) Miramichi rivers for the smolt migration years 1996 to 2018 (top row). The bottom row shows the relative survival rates during the first year at sea plotted against the estimated (log scale) Striped Bass spawner abundances in the Miramichi River for the corresponding smolt and Striped Bass spawning years 1996 to 2018. The solid blue line is the linear regression of relative survival rates to log of Striped Bass abundances for the 2003 to 2016 years corresponding to the acoustic tagged smolt survival time series of the Miramichi River (see Figure 9).

Conclusions on species interactions

There is contradictory evidence of reductions in examined anadromous fish abundance indicators associated with increased abundance of Striped Bass in the southern Gulf. For gaspereau, recorded commercial landings have greatly declined in Gulf NB portion, since 2005.

Catches from estuarine index trapnets also show declines, beginning in 2005, but less severe than indicated by the commercial landings. Commercial landings of Rainbow Smelt have also greatly declined in the Gulf NB portion since 2005 whereas American Shad indicators from the estuary trapnets have increased. For Atlantic Salmon, there is direct evidence of predation by Striped Bass on Atlantic Salmon smolts. Studies using acoustic tags placed in salmon smolts have inferred predation events and changes in survival rates during the early phase of migration through Miramichi Bay, with the lowest survival rates estimated for the years when Striped Bass spawner abundances exceeded approximately 100 thousand spawners. Population level effects are contradictory between the two branches of the Miramichi, with relative survival rates for the Southwest Miramichi showing a negative association with Striped Bass abundance indices for the years 2003 to 2016 but not for the Northwest Miramichi.

Management Considerations

Fisheries management actions were responsive to the decline and rebuilding of the Striped Bass population beginning with the closure of all directed fisheries for Striped Bass in 2000, followed twelve years later with the re-opening of the Indigenous FSC fisheries in 2012, and the retention recreational fisheries in 2013. The re-opening of the Indigenous fishery occurred following the conclusion that the Striped Bass population in 2011 had first achieved both the limit and target recovery objectives, at a median abundance of 200 thousand spawners and a 5th percentile value of 90 thousand spawners (DFO 2013). A cautious recreational fisheries strategy (two short retention seasons, 1 fish per day, slot size limit of 55 to 65 cm TL) was chosen in 2013. Further increases in abundance in 2015, to a median estimate of 300 thousand spawners, resulted in an extended retention period in the recreational fishery for 2016. The largest change in the recreational fishery access occurred in 2018 with an authorization to retain 3 fish per day, following on the exceptional abundance estimate in 2017 of just under 1 million spawners. The pilot commercial fishery was also first authorized in 2018. This increased fisheries access occurred as the stock abundance was on a trajectory of increasing abundance from the critical zone to the cautious zone as defined in this assessment.

New and alternative fisheries access requests could be anticipated when the assessed abundance of Striped Bass surpasses the USR and be situated in the healthy zone. The fisheries exploitation potential on this species is high. During the spawning aggregations Striped Bass are captured in large numbers in gaspereau trapnets in the Miramichi with catch rates (fish per trapnet per day) that can exceed several thousand fish per net haul (DFO 2020). Striped Bass are also reportedly captured in high numbers in gaspereau fishery trapnets in other estuaries of DFO Gulf New Brunswick. Following on the expanded distribution of bass to the north shore of the St. Lawrence and Labrador in 2017, important Striped Bass harvests were reported from this northern area (DFO 2018) and the presence and harvest of Striped Bass that remained from the 2017 emigration from the southern Gulf continue to be reported from this northern area.

The recreational fishery is increasing in popularity throughout the Gulf of St. Lawrence, including westward to the north shore of the Gaspe Peninsula (Quebec). The current recreational fisheries management plan that provides a three fish daily and possession limit is the highest allocation of any jurisdiction in eastern North America. There is a one fish daily and possession limit in the DFO Maritimes Region management area as well as in the eastern US, with size limits dependent on region.

Slot size limits have been in place for the southern Gulf recreational fisheries since 2013. The slot size minimum length is intended to reduce the exploitation on younger fish until they have had an opportunity to spawn once whereas the maximum length of the slot is intended to protect older fish of higher fecundity and to maintain a spawning pool to guard against successive year classes of poor recruitment. Slot size measures are considered to be superior to other size limit strategies as a compromise regulation for achieving competing objectives of different users. The use of size limits in fisheries results in catch and release of fish that are outside the size window for retention. The recreational fishery for Striped Bass in the southern Gulf has a large component of catch and release, in part due to the mandatory slot size restrictions for retention but also associated with the fishing practices of individual anglers that favour a lot of angling activity without intent to retain.

There are very limited catch data from the recreational fishery and the consequences of retentions as well as catch and release mortality on the productivity of the population are unknown. A catch and release mortality rate of 9% is assumed in the coastwide Striped Bass assessment of the US but the catch and release mortality rate has been shown to depend upon the fishing gear, water temperature, maturity state and angler practices (NEFSC 2019). In the southern Gulf, there is a large angler presence and quantities of Striped Bass are caught and released on pre-spawning and spawning aggregations of Striped Bass in May and June in the Miramichi River. There may be non-mortality consequences to individual fish (releasing of milt and eggs when fish are handled and released, disruption of spawning behaviour) and to the spawning population of angling activities and catches at that time of year. Since 2017, short term closures of all recreational fishing in sections of the Northwest Miramichi of 5 to 9 days depending on the year have been implemented when spawning activities have been reported to DFO Fisheries Management. Such closures would reduce some of the acute and chronic consequences of recreational fishing on spawners.

Sources of Uncertainty

The Striped Bass population of the southern Gulf of St. Lawrence has been monitored annually since 1994. The estimated number of spawners is assessed using catch rates from the commercial gaspereau fishery in the Northwest Miramichi. There are large uncertainties in the annual estimates (coefficient of variation range 6% to 91%) however the near monotonically increasing abundance from approximately 5,000 spawners in the late 1990s to over 300 thousand since 2016 is confirmed from the catches by month and overall at the DFO index trapnets in the Miramichi.

Life history characteristics and population dynamics parameters required for population modelling are known with varying degrees of uncertainty. The length-weight relationship and the fork length-at-age, based on interpretations of scales, is well described from sampling data. The oldest age determined from scales for this population is 15 years. Scales are reported to underestimate the age of bass older than 8 years. Bass are relatively slow growing after age 8 to 10 years (fork lengths greater than 65 cm for this population), at less than 2 cm fork length per year. An age-length key, derived from samples obtained over years and analyzed using a von Bertalanffy growth model, is used to translate the size distribution of spawners to an age distribution. The bias introduced from this underestimation of age using scales is to overestimate the growth rate based on the model and by using the age-length key to underestimate the abundance of older fish in the population. The use of a plus group at age 15 in the age-length key addresses in part the underestimation of older fish, but older fish would remain underrepresented in the population overall, and bass at younger ages overrepresented to some degree. Collectively, this would result in overestimation of survival of the younger ages and underestimation of survival of the older ages.

Differences in growth rate, size-at-age, and weight-at-length between male and female bass are also reported in literature, aspects which are not considered in the population model that aggregates male and female abundances and their population dynamics. Maturity schedules are assumed based on assumptions from other studies and limited observations that males mature earlier than females; the resultant proportion female at age of the spawners is supported by observations from intensive sacrifice sampling of Striped Bass on the spawning grounds in recent years. Fecundity at age is not known for this population and a fixed value of eggs per kg was borrowed from other studies. The scale of the uncertainties and the bias these may introduce in the modelling of the population dynamics were not quantified. The uncertainties are considered to be small relative to the estimation of other population dynamics parameters (stock and recruitment parameters, mortality) from the model.

Mortality rates of young age classes, including overwinter mortality of age 0 and mortality-at-ages 1 and 2 years, are not known. Mortality rates of the younger age groups are expected to be high, based on general inverse relationships of size-at-age and mortality. The Striped Bass population of the southern Gulf is also at the northern limit of the species distribution and environmental conditions that modify the size of the young-of-the-year going into their first winter and the overwintering conditions through which Striped Bass fast, are important contributing factors that result in unpredictable survival rates among cohorts. Uncertainties in the mortality rates of younger ages have consequences in population models that assume a stock and recruitment relationship from eggs to age 0 in the first summer. There are no observations of relative abundance of these age groups; observations of spawners begin at age 3. Due to the lack of data at those younger ages, two models with differing equations for mortality rates from age 0 to age 3 are carried forward in the derivation of reference points.

Despite the closure of the directed fisheries for Striped Bass, fishing mortality mostly associated with illegal fisheries was considered to have continued. The directed recreational retention fisheries subsequently reopened in 2013. In the absence of fisheries harvests, the estimates of mortality from the population modelling are considered to be total mortality. Natural mortality (M) rates are required for calculating maximum sustainable yield. Acoustic tagging and tracking data from 2003 to 2018 provide estimates of total mortality of larger (> 40 cm) Striped Bass. The total instantaneous mortality (Z) estimate for the years 2014 to 2018 was 0.22 (median). Fish which overwintered in areas other than Miramichi would have been considered a mortality if there were no detections in subsequent years in the Miramichi. With this in mind, and the fact that some mortalities would have been associated with fishing, there is high certainty that the instantaneous natural mortality is very likely no higher than 0.2, the value ultimately used in the equilibrium modelling to define reference points.

It was assumed that there is a density dependent compensatory function between eggs spawned and production of young-of-the-year in the first summer. Other studies have reported that inter-year class variability in Striped Bass is high, largely determined during the egg and larval stages, and influenced by environmental factors. The population models used also consider the recruitment dynamic from eggs to young of the year as a stationary process thus ignoring the non-stationary variation in survival associated with auto-correlated variations in environmental conditions. The consequences of environmental variation begin at the egg and larval stage, and carryover into variable conditions that affect growth during their first summer with subsequent consequences associated with size biased survival of larger bodied young of the year during the first winter. A population model that ignores these non-stationary events that affect survival will not adequately characterize the variations in cohort strength that are otherwise assumed to be determined by spawner abundance and temporally independent stochastic variability. Some of these dynamics could be incorporated in the equilibrium modelling as stochastic and probabilistically determined events that change the probability of survival of a cohort in order to assess the consequences of these events on the derivation of the reference points; until these analyses are completed, the consequences are not known.

Based on the available observations, the stock and recruitment dynamic is adequately described by a proportional function or Beverton-Holt stock and recruitment function. The near monotonic increasing trajectory of the population abundance from its low point in the late 1990s to the highest abundance in the late 2010s provides limited information to unequivocally define the unfished population size. The conclusion from population modelling with the available data is that the maximum abundance for this population has not yet been realized. The recruitment from the 2017 to 2019 spawner abundances have not been assessed with 3-year olds from the 2017 spawning first available for assessment in 2020, and the other year classes in 2021 and 2022.

There is compelling evidence that the Northwest Miramichi River is the major spawning area for the Striped Bass population of the southern Gulf of St. Lawrence and the assessment data and population model assume that this is the only area that produces recruitment. Recently, eggs and larvae of Striped Bass have been sampled from geographically proximate tidal areas to the Northwest Miramichi during a period of high Striped Bass spawner abundance. Observations of spawning activities outside the Northwest Miramichi would be expected as the overall spawner abundance increases. The establishment of new spawning areas is possible as evidenced from the results of the restoration program of the St. Lawrence River. The consequence to population modelling of not considering other spawning areas depends upon whether there are exchanges of recruitment and spawners between the spawning areas. If there are exchanges, then the carrying capacity would currently be underestimated although density independent survival rates from eggs to age 0 in summer would likely not be as this is a characteristic specific to the spawning location. Currently, the assessment in the Northwest Miramichi is the only and best available information on both the spawners and recruitment of Striped Bass in the southern Gulf.

The most important uncertainty in understanding the population dynamics of the Striped Bass population of the southern Gulf of St. Lawrence is the near total absence of fisheries catches and harvest data. In the absence of catch and harvest data from all the fisheries, the best that could be done is to track the response of the population abundances to variations in fisheries management strategies. The variations in abundance could not be partitioned into components related to fishing which leaves the dynamic and robustness of this population to fishing and environmental variations unknown.

There is contradictory evidence of reductions in examined anadromous fish abundance indicators associated with increased abundance of Striped Bass in the southern Gulf. Correlation analyses are a first step in examining the potential interactions but they do not demonstrate cause and effect. A carefully designed ecological experiment with long-term monitoring would be required to resolve the question of these species interactions.

CONCLUSIONS AND ADVICE

The Recovery Potential Assessment (RPA) of the southern Gulf Striped Bass population conducted in 2006 proposed abundance recovery objectives intended to guide management actions that would promote recovery of the population (DFO 2006; Douglas et al. 2006). The RPA recovery objectives were never intended to be reference points that conformed to the PA. At the time of the RPA, there were twelve years of spawner abundance estimates available with the maximum median estimate of 28,000 fish in the early 2000s, that followed on the very low abundances of the late 1990s. The RPA objectives were first exceeded in 2011; the median spawner abundance in that year had been estimated at 200 thousand spawners (DFO 2013). The available series of assessed abundances to 2019 and the population modelling to define reference points provide a much higher potential population size than was derived during the RPA with data available to 2006. The RPA recovery objectives are not appropriate for managing fisheries on this population of Striped Bass.

An Upper Stock Reference (USR) point conditional on fishing strategy is consistent with the Precautionary Approach (PA) policy; the USR could reflect socio-economic considerations. The 80% Bmsy definition has been most frequently used in fisheries management and is proposed as the USR. There is no model consensus for the USR value. An Upper Stock Reference value equivalent to 720 thousand spawners, based on Model 4, was only surpassed in 2017. The carrying capacity of the Striped Bass southern Gulf population is very uncertain. The equilibrium modelled abundances of age 3 and older Striped Bass at Bmsy are 1 to 2 million fish, 0.7 to 1.2 million spawners, depending on the model. Potential removals when the stock is at Bmsy are in the range of 200 to 400 thousand fish annually.

Based on the PA policy, the LRP should be determined by biological considerations and preferably invariant to fisheries exploitation strategies. Brecover, the lowest historical spawner abundance that did not prevent rebuilding of the population, is not considered an appropriate LRP for this Striped Bass population. Eggs for half saturation (half the Beverton-Holt carrying capacity value) is proposed for the LRP; equivalent values in units of spawner number and spawner biomass are also provided. There is no model consensus for the LRP value. Based on the trajectory of this population over the relatively short period of assessment, maintaining spawners above 330 thousand fish (median of the LRP equivalent value from Model 4) should be sufficient to avoid serious harm.

A USR value of minimally 720 thousand spawners may underestimate the production potential however full exploitation to rates equivalent to Fmsy and potential removals at MSY (Cmsy) would likely only be considered once the trajectory of the population had placed the abundance in the healthy zone. A re-assessment of population dynamics with additional observations could be undertaken at that time to determine the appropriateness of the defined USR and LRP.

The recent fisheries management history is informative of the management decision making process in response to increased abundance. Fisheries access was responsive to the rebuilding of the Striped Bass population beginning initially with the re-opening of the Indigenous FSC fisheries in 2012, the retention recreational fisheries in 2013, and a pilot commercial fishery in 2018. Fisheries were gradually reopened and access increased as the spawner abundances progressed from levels that were in the proposed critical zone, increasing to the LRP and eventually to the cautious zone by 2019.

The exceptional 2017 value of approximately one million spawners and the decline in 2018 and 2019 to just over 300 thousand spawners provides a cautionary note on variations in size of the stock under new population dynamics conditions (extensive migration of Striped Bass beyond its historic distribution range with associated mortalities) and increasing fisheries exploitation.

In the absence of any monitoring of recreational catches and harvests, it is not possible to provide fisheries management advice in terms of total allowable catches nor can the status of the population be assessed relative to directed fisheries losses (retention and catch and release mortality). More importantly, the absence of catch and harvest data from all the fisheries precludes understanding the causes of variations in assessed spawner abundances of Striped Bass which leaves the dynamic and robustness of this population to fishing and environmental variations uncertain.

Stomach content analyses provide direct evidence of predation by Striped Bass on Rainbow Smelt, gaspereau and Atlantic Salmon smolts in the Miramichi River. There is contradictory evidence that the reductions in examined anadromous fish abundance indicators were correlated with increased predation by Striped Bass in the southern Gulf. It is not clear that reducing Striped Bass spawner abundances to lower levels would improve any of the indices of the examined anadromous species including landings of gaspereau and Rainbow Smelt in the commercial fisheries and indices of acoustic tagged smolt survival rates in the Miramichi. Alternate reference levels to address the multiple species concerns cannot be defined based on the available information. Setting a management objective for Striped Bass that is less than the defined LRP would reduce the potential yields of the Striped Bass directed fishery and be non-compliant with the PA policy (DFO 2009).

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This Science Advisory Report is from the regional advisory meeting of November 23-25, 2020 on Reference points that conform to the Precautionary Approach for the Striped Bass population of the southern Gulf of St. Lawrence. Additional publications from this process will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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