Bob Sam
Sitka Tribe

Part 2 of 6

RC 28

Status of Southeast Alaska, Sitka Sound, and British Columbia Herring

Status of herring in Southeast Alaska during the early and mid-1900s must be inferred from commercial herring harvests because spawning biomass was not consistently estimated until 1980 or so. Commercial herring harvests in Southeast Alaska began in the late 1800s, then surged to exceptionally high levels from about 1925 to 1940 when up to 80,000 tons were harvested per year (Fig. 1; Thornton et al. 2010a, b). Annual harvests declined to ~15,000-50,000 tons during the 1940s and 1950s, then declined to less than 10,000 tons during the late 1960s, 1970s, and early 1980s presumably reflecting the decline in total herring biomass. Annual harvests increased during the 1990s to 2000s, reached a peak in 2010 at 24,770 tons, then declined during the past seven years (Fig. 1).

Total spawning biomass of major herring stocks in Southeast Alaska was relatively constant at ~75,000 tons per year during 1980 to 1997, increasing to ~160,000 tons in the late 2000s, then steadily declining to ~75,000 tons during 2014-2017 (no data for 2018) (Fig. 2). Spawning biomass trends are similar with and without Sitka Sound herring (Fig. 2), which is the largest herring population in Southeast Alaska, indicating that some large-scale factor influenced the overall declining herring trend in Southeast Alaska. During the past 10 years, a number of herring fisheries have been permanently or intermittently closed to commercial fishing in response to low herring biomass (Coonradt et al. 2018, Thynes et al. 2018). Only the Sitka Sound herring fishery has been open to commercial fishing each of the past 35 years.

Overfishing is considered the key reason for the decline of herring during the early and mid-1900s (NMFS 2014). Furthermore, Thornton et al. (2010a, b) suggest that *"while herring might now be managed conservatively—herring are being managed in a significantly depleted state."* In other words, the baseline of herring abundance has shifted downward and the herring populations have not been able to rebound. In support of this concept, Thornton et al. (2010a) noted that a survey of traditional ecological knowledge (TEK) documents a history of 2,759 miles of herring spawn in Southeast Alaska (c.1915–present) compared with 1,118 miles of spawn recorded by ADF&G during 1970–2007. In contrast, NMFS (2014) notes that some of this discrepancy in herring spawning distribution reflects areas that were not surveyed by ADF&G rather than areas devoid of spawn. As discussed below, contraction of spawning areas often occurs in response to declining abundance of herring. At this time, we do not know the harvest rate of the herring reduction fishery during the 1920s and 1930s when up to 80,000 tons were harvested each year so it is difficult to compare these earlier values with the present. However, as noted above, spawning biomass in Southeast Alaska, based on egg surveys[1], peaked near 160,000 tons in the late 2000s before declining in recent years.

[1] As noted below, there is some evidence in Sitka Sound that field egg surveys led to higher biomass estimates than the ASA modeled approach but only at the highest biomass values. This pattern is evident by comparing field-derived spawning biomass values in Fig. 2 with modeled values in Fig. 3. ADF&G considers the modeled values to be more accurate (Hebert 2017).

Population Structure

NMFS (2014) assessed the population structure of herring in Southeast Alaska. They concluded that all herring stocks in Southeast Alaska are part of the same distinct population segment (DPS), which extends from Dixon Entrance northward to Cape Fairweather and Icy Point. Delineation of the southern boundary is based on genetic differences between herring in Southeast Alaska and those in British Columbia, plus differences in recruitment, average weight-at-age, parasitism, spawn timing and locations, and the results of tagging studies in British Columbia. The northern boundary is defined by physical and ecological features that create migratory barriers, and large stretches of exposed ocean beaches that are devoid of herring spawning and rearing habitats.

NMFS (2014) recognized the possibility that there may be subpopulations within the Southeast Alaska DPS, and that these subpopulations require separate management. For example, genetic structure of herring from Sitka Sound and other outer coast herring was different from those in Berners Bay Lynn Canal. In contrast, other studies indicated very little differentiation between samples combined within Sitka Sound, Mary Island/Kirk Point, and Seymour Canal. We are unaware of studies that have evaluated genetic differences between "waves" of spawning herring in an area such as Sitka Sound but we suspect it is likely minimal. Although some studies indicate environmental differences may have reduced gene flow in some regions of Southeast Alaska and corresponding adaptions have occurred in herring in outer coastal as compared to interior waterways, NMFS (2014) concluded that the data do not contradict the DPS delineation for herring in Southeast Alaska. Southeast Alaska herring fit the definition of a metapopulation, that is *"a system of discrete local populations, each of which determines its own internal dynamics to a large extent, but with a degree of identifiable and nontrivial demographic influence from other local populations through dispersal of individuals."*

Sitka Sound Herring Status

Sitka Sound supports a major component of herring in Southeast Alaska, and total herring biomass has been estimated by ADF&G since 1969. During the so-called "developing years" from 1969-1978, total herring biomass averaged 5,883 tons and spawning biomass averaged 5,346 tons. Also, only 11.5 miles of spawn were documented, on average (Davidson et al. 2010). Herring biomass increased substantially after 1979, probably in response to the 1977 ocean climate regime shift, at least initially (Anderson and Piatt 1999). From 1980 to 1995, total herring biomass and spawning biomass increased to 40,000 and 35,000 tons, on average, then steadily increased until peaking at approximately 117,000 tons in 2009 (total biomass) (Fig. 3). Thereafter, total biomass and spawning biomass declined steadily over time to approximately 63,000 and 49,000 tons, respectively, in 2017. During the recent period of decline (~2011 to 2017), commercial harvests averaged 12,650 tons, or 16.3% of the total mature biomass (Fig. 3). In 2018, the apparent biomass and quality (size) of herring unexpectedly declined much further. Total biomass and spawning biomass estimates for 2018 are not yet available but the nautical miles of spawn (32 nm) was the lowest on record since 1979. Details about the commercial fishery and its management are described below.

The time trend of spawning biomass per mile of spawn (i.e., average spawn density) largely follows the biomass trend, except spawn density began to decline after 2005 rather than after 2009 (Fig. 4). Nautical miles of spawn varied year to year but without a long-term trend. Nautical miles of spawn only explained approximately 10% of the annual variability in spawning biomass, 1980-2017. In other words, spawning density was key to overall spawn biomass. Peak spawn density occurred in 2005 (2,116 tons/nm), then declined steadily to relatively low densities in 2015 (653 tons/nm) and 2017 (766 tons/nm)(Fig. 4). At present, spawning density is similar to the low density period from 1980 to 1994 (avg. 572 tons/nm). The exceptionally low nautical miles of spawn in 2018 is unusual given that overall nautical miles of spawn was relatively stable until 2018. The declining density of spawn since 2005 seems to explain in part the growing concern by STA subsistence users about their inability to meet subsistence needs.

ADF&G regularly monitors herring age and size as part of the management effort. Age composition from cast net sampling along the spawning areas highlights relatively strong year class recruitment in 1988, 1991, 2003, and 2015 (Fig. 5). Relatively abundant age-3 herring in 2015 should have been a key component of the 2018 run (as age-6 fish; 2018 age data are not yet available). During 2015 to 2017, the diversity of age composition appears to be relatively low, a factor that may have contributed to the low return in 2018. NMFS (2014) reported slightly older herring, on average, along Sitka Sound spawning grounds during 2001-2011 compared with 1988-1999.

Average weight at age of Sitka Sound herring tended to increase from 1991 to 2002, then decline slightly thereafter (Fig. 6). Condition factor, which reflects weight and length, increased from 1991 to 1997 then followed a cyclical pattern (Fig. 7). High correlation in the condition of all age groups suggests common factors affecting each age group. Hebert (2017a) noted that size at age of Sitka Sound herring tends to be greater than that of other herring stocks in SEAK, especially at older ages, perhaps reflecting their proximity to open ocean feeding grounds. For most SEAK stocks, weight of age-3 herring has been stable over the past few decades, while weight of other ages has gradually declined, especially among oldest age classes.

British Columbia Herring Status

Herring populations in British Columbia have been managed using an approach similar to that in Southeast Alaska, so it is worthwhile to examine status and management of these populations. Furthermore, First Nations in British Columbia have raised similar concerns about management of herring (McCall et al. 2018).

Approximately 5,347 km (or 18 %) of British Columbia's extensive 29,500 km coastline have been ranked and classified as herring spawning habitat. A much smaller portion (300-600 km) is utilized every year by first time and repeat spawners.

Herring in British Columbia collapsed in the mid-1960s, then began to recover several years later in the early 1970s after several years of nearly zero commercial catch (Fig. 8). By the late

1970s, spawning biomass had recovered to approximately 550,000 tons per year (250,000 metric tons), with herring spawning in both new and old areas. However, some previously abundant spawning areas were not re-colonized. In spite of relatively low catch levels since the collapse in the 1960, herring spawning biomass declined steadily from the 1980s through the 2000s, but has begun to increase in recent years (Fig. 8). Over the decades, the Department of Fisheries and Oceans Canada (DFO) has observed long-term episodic redistributions of herring that are associated with population spikes or pulses (discussed further below).

Total biomass and spawning biomass of herring in the five major regions of British Columbia are shown in Fig. 9. All stocks except for Strait of Georgia (increase then decrease) have experienced a downward decline from the 1980s to 2011. Commercial harvests in the herring sac-roe fishery have been relatively low for several decades and especially low in recent years (Fig. 10).

Age composition of herring has gradually changed over time since the early 1980s; fewer older herring occur in the recent period (Fig. 11; Martell et al. 2012). This pattern corresponds with the declining biomass shown in Fig. 8. From the mid-1970s until the present, there has been a measurable decline in weight-at-age for all ages in all major stock areas (Fig. 12). Weight at age collected during the 2009/2010 fishing year (most recent values) were among the lowest on record. Martell et al. (2012) note that declining weight-at-age may be attributed to any number of factors, including: fishing effects (i.e., gear selectivity), environmental effects (changes in ocean productivity), or to changes in sampling protocols (shorter time frame over which samples are collected). Declining weight-at-age has been observed in all five of the major stocks, and despite area closures over the last 10-years, has continued to occur in the Haida Gwaii (HG) and west coast Vancouver Island stocks. Martell et al. (2012) state that the weight at age trend has been observed in B.C. and U.S. waters, from California to Alaska. The direct cause of this decline requires further research.

Sitka Sound Subsistence Herring Fishery

Subsistence herring fisheries that harvest roe on substrate have a relatively small impact on future herring production compared with the commercial fisheries. STA estimates that the amount of roe taken by the subsistence fishery is about 5% of the roe harvested by the commercial fishery (Erickson 2017). Furthermore, adult herring are not harvested when gathering roe on hemlock branches, so spawned herring can potentially spawn in subsequent years. In contrast, adult herring are harvested in the commercial sac-roe fishery and do not have the opportunity to spawn in subsequent years.

Sitka Sound supports the largest herring subsistence fishery in Alaska. In contemporary times, herring roe on substrate, especially hemlock branches, is targeted by Sitka Sound subsistence fishers rather than whole herring. Subsistence use of herring in Sitka Sound has a long history, and herring was a key reason why people settled in this region (Thornton et al. 2010a, b). Although people throughout Southeast Alaska come to Sitka Sound to harvest herring roe, in 2016 approximately 51% of herring roe was shipped out of Sitka, 46% was shared with other people within Sitka, and only 3% were kept for own use (Sill and Cunningham 2017). In other words, herring roe in Sitka Sound supports a much broader range of subsistence users than might be expected in this relatively remote location. Sharing of subsistence food is common across Alaska.

Subsistence harvests of herring roe from Sitka Sound have been estimated since about 2002, a period when up to 72% of households attempted to harvest herring roe. Roe harvests peaked in 2004 at 381,000 ± 61,000 lbs (± 95% CI) and have generally declined over time, especially since 2014 (Fig. 13; Sill and Cunningham 2017). Subsistence roe harvest quantities are not yet available for 2017 and 2018, but they are likely below the amount needed for subsistence (ANS = 136,000 to 227,000 lbs). The current level of ANS, which was established by the Board of Fisheries in 2009, is considerably lower than the 700,000 lbs of roe summed from 72 letters of roe needs submitted by tribal households in 2009.

During the past 14 years (2005-2018), subsistence harvests have exceeded the lower amount needed for subsistence (136,000 lbs) in only 4 years (Fig. 13). Low subsistence harvests are related to less opportunity to harvest quality eggs in accessible locations and to the amount of effort (Sill and Cunningham 2017). Good quality eggs cover the substrate several layers deep and lack impurities, such as sand; thickness of egg deposition is related to the number of days of spawning activity plus size and density of the school of spawning herring. In 2016, approximately 30% of harvesters stated "resource availability" as the reason for decreased harvests, while about 35% listed "poor quality" spawn as the reason. STA believes that lower subsistence effort in recent years, as shown in Fig. 13, is not the primary driver of low harvest levels; rather the key driver is the amount and quality of spawn[2]. Erickson (2017) stated that numerous tribal elders have testified that herring spawning in Sitka Sound has decreased in duration and amount and have become more unpredictable across the spawning season and across the traditional spawning locations.

In 2012, the Board of Fisheries (BOF) established the "Core Conservation Area" (5 AAC 27.150) to help protect the subsistence harvest area. However, the Core Conservation Area included only ~50% of the subsistence use area, according to STA. In 2018, the area closed to commercial fishing was expanded by the Board of Fisheries to include more but not all of the area used by subsistence fishers (Fig. 14 and 15). Fig. 16 shows maps of Sitka Sound herring spawning locations, commercial fishing areas, and areas closed to commercial fishing, 2008-

[2] Reduced effort involves individuals that are less efficient at harvesting roe. Less efficient harvesters stop fishing during periods of few eggs because it is not worth the effort.

2017. Locations of subsistence fishing are relatively static whereas the commercial fishery adjusts to the location of spawning herring each year. The flexibility of the commercial fishing fleet to easily move from area to area and the inability of most subsistence users to follow the spawn are important reasons for opposite harvest trends of these two user groups.

ADFG conducts aerial surveys of Sitka Sound shorelines to document miles of herring spawn each year, 1964 to present. The distribution of herring spawn changes from year to year, as shown in annual spawn maps produced by ADF&G. Areas of subsistence fishing encompass those beaches in Sitka Sound that have been most frequently used by spawning herring since at least 1964 (Fig. 17). Herring spawned throughout much of the subsistence use area in most of the past 47 years.

In 2018, however, only 32 nautical miles of spawn were recorded and the area typically used by subsistence fishers was largely devoid of spawning herring (Coonradt 2018). Miles of spawn in 2018 was the lowest since 1979. ADF&G noted that while the miles of spawn was small, the egg deposition along Kruzof Island extended farther offshore and was more dense than normal. Spawning biomass estimates for 2018 are not yet available to evaluate the extent to which density compensated for few miles of spawn. Regardless, the lack of spawn within the traditional subsistence use area prevented most Tribal members from meeting their herring roe needs.

STA expressed concern that recent aerial (and skiff) survey maps of herring spawning locations overestimated the distribution of spawning activity and biomass because STA harvesters sometimes see few eggs in areas reported to have spawn. ADF&G ground truths aerial spawning estimates with field sampling often within 10 days of the spawning event because 10% to 35% of eggs may be lost to predators and environmental stresses (Hebert 2017a). These field surveys are used to estimate spawning biomass of herring, but they are considered by ADF&G to be less reliable for estimating overall spawn biomass compared with the ASA model estimates. Modeled estimates of spawning biomass have been much less than field-based estimates when the field-based values exceeded 105,000 tons, otherwise the values were highly correlated and nearly 1:1. This discrepancy should be investigated. In 2017, spawn deposition surveys were conducted at 52 transects within the 44 nm of spawn during the first spawn period; 15 transects were surveyed during the second period. Guideline harvest levels are based on the ASA modeled estimates of biomass rather than the field estimates. Confidence levels should be shown with modeled and field derived biomass estimates so that the level of certainty can be assessed.

Sitka Sound Commercial Herring Fishery

Commercial harvests of herring in Southeast Alaska began in the late 1800s. From 1925 to 1940 up to 80,000 tons of herring were harvested per year in the reduction fishery, then harvests significantly declined in response to overfishing (Thornton et al. 2010a, b). A large fraction of these harvests occurred in Sitka Sound.

In Sitka Sound, the sac roe fishery harvested 654 tons of herring per year during 1969 to 1978, or approximately 11% of the total herring run (Davidson et al. 2010). Harvests increased to 5,719 tons per year, 1980-1995, and further increased to 19,539 tons in 2011 before decreasing to only 2,226 tons in 2018 (Fig. 3). The maximum observed harvest rate since 1980 was 27.9% in 1993. During 2011 to 2017, the harvest rate averaged 16.3% (range: 7.4% to 24.6%). Although the spawning density of herring has steadily declined from 2,100 tons/nm in 2005 to 766 tons/nm in 2017 (Fig. 4), harvest levels in the commercial fishery have remained relatively constant except for low harvests in 2013 and 2018 (Fig. 3).

Herring Management in Sitka Sound

Herring in Sitka Sound and throughout Southeast Alaska have been managed using a threshold and variable harvest rate policy since 1983. Thresholds are biomass reference levels established for each fishing area. If the spawning biomass in an area is forecast to be below its threshold, then no harvest is allowed. In Sitka Sound, the threshold has increased from 7,500 in 1983 to 20,000 in 1997 and to 25,000 tons in 2010. The 20,000 ton threshold stemmed from an assessment to determine 25% of the estimated average unfished biomass of herring, an approach that is used throughout Alaska and British Columbia (Carlile 1998). The assessment to estimate the average unfished biomass of herring is critical to protecting herring during periods of low abundance such as may occur during unfavorable climate and ocean conditions (DFO 2017). In Sitka Sound, the estimate of unfished biomass was based on a period of relatively low herring abundance and it has not been re-evaluated since 1998. Re-analysis of the unfished herring biomass using all available data is critical for sustainable management of the herring population.

Throughout most of Southeast Alaska, the exploitation rate is 10% of the total biomass when the forecasted total biomass for an area meets or initially exceeds the threshold. For each incremental increase in the total biomass equal to the threshold, the exploitation rate increases by 2%. The maximum 20% exploitation rate is achieved when the total biomass is six times the threshold level.

In Sitka Sound, however, a more aggressive harvest rate is used once the threshold has been reached (Fig. 18). The initial harvest rate is 12% rather than 10%, and the maximum 20% harvest rate is reached at 1.8 times rather than 6 times the threshold level[3]. The biological basis for the higher harvest rate of the Sitka Sound fishery is not apparent. The Board of

[3] Sitka Sound maximum harvest rate of 20% = 2+8*(45,000/20,000), or 1.8 times the threshold of 25,000 tons.

Fisheries raised the initial harvest rate in Sitka Sound from 10% to 12% while also raising the harvest threshold from 20,000 to 25,000 tons. The sliding scale harvest rate is applied to the pre-season total herring biomass forecast in order to set the guideline harvest level. The decline in herring biomass in Sitka Sound is coincident with the implementation of the more aggressive harvest rate schedule beginning in 2010. A thorough critique of this aggressive harvest rate and an analysis of unfished biomass is needed as a means to ensure sustainable harvests, especially for subsistence fishers that have priority in Alaska.

During the herring fishing season, ADF&G monitors herring distribution and roe quality prior to and during the fishing periods (Thynes et al. 2018). Monitoring methods include aerial surveys, vessel sonar surveys, and test fishing. ADF&G typically coordinates with industry seine vessels to conduct test fishing as necessary to determine roe quality. Prior to making test sets, the test boats contact ADF&G biologists on the grounds to monitor set locations and to plan for transport of herring samples to a central location for analysis by industry technicians. The areas open to fishing depend on the distribution, abundance and quality of herring, and *"the need to provide a reasonable opportunity for subsistence."* In 2018, the BOF modified 5 AAC 27.150(a)(4) and expanded the commercial fishery closed waters in Sitka Sound (Fig. 15). According to ADF&G, the expansion of the closed waters was intended to reduce "perceived" conflict of commercial harvest with the subsistence harvest of herring roe-on-branch. According to ADF&G, it manages the commercial sac roe fishery while considering the subsistence fishery by dispersing the commercial harvest consistent with 5 AAC 27.195. Maps of the commercial fishing areas in relation to herring spawn distribution show that the commercial fishery targets the herring spawning areas while avoiding waters closed to protect subsistence fishing since 2013 (Fig. 16).

However, the commercial fishery is often allowed to capture herring immediately adjacent to the closed area boundary. Sitka Tribal members and staff consistently state that commercial fishing activities, including the test fishery, cause herring to begin spawning prematurely in areas of unsuitable habitat. Furthermore, they believe that fishing activities stimulate herring to spawn in nearby areas rather than in areas where they would normally spawn. Effects of commercial fishing during the spawning period of fishes have been reviewed in terms of sustainable fisheries (van Overzee and Rijnsdorp 2014). Further documentation of these observations among Sitka Sound herring is needed.

<u>Implementation of the Harvest Rule in Sitka Sound</u>

The key component of setting the guideline harvest level in Southeast Alaska, including Sitka Sound, is the pre-season forecast of herring biomass because it determines the exploitation rate and the herring biomass that will be targeted. Forecasts of the upcoming herring run are developed using ASA, a common approach for herring in Alaska and BC. This method applies estimates of recruitment, growth, maturation, and natural mortality to an estimate of spawning escapement in the current year to forecast herring biomass in the next year.

Accuracy of pre-season forecasts is critical for managing the fishery and protecting herring from overharvest. In Sitka Sound, forecasts underestimated biomass in 29 of the past 38 years (75%; 2018 data incomplete), or approximately 11,000 tons per year, 1980-2017 (Fig. 19). In other words, the low forecasts led to guidelines harvest levels that were typically smaller than if forecasts were perfect. From 2011-2017, forecasts underestimated biomass in 4 of 7 years (57%)(Fig. 19). In 2012, the forecast was 1.8 times larger than the run, but the observed harvest rate was only 16.7% which was less than the 20% allowable harvest rate. Over forecasting the biomass of herring is more likely during periods of declining abundance. For this reason, it is important for forecasting methods and models to incorporate factors, such as oceanographic events (climate change), or other approaches (i.e., time series) in an attempt to anticipate the downward trend as shown in recent years. Forecasts should include confidence levels as a means to communicate the level of uncertainty in the forecasts.

ADF&G manages the commercial fishery with the intent to meet the guideline harvest level. Herring harvests exceeded the GHL in 20 of the past 39 years (51% of years), but the level of exceedance was typically small and actual overall harvests averaged less than the GHL by 690 tons per year (Fig. 19). Since 2011, harvests have been below the GHL by 4,270 tons, on average. This value includes 2018 when the size of herring and quality of spawn was not adequate and the fishery closed early before reaching the GHL. The estimated harvest rate on herring averaged 14.7% during 1980-2017, and 16.3% during 2011-2017. The maximum allowable harvest rate (20%) was exceeded in 7 of 38 years (18%), averaging a harvest rate of 23.9% in these years.

Another way to examine harvest management is to compare observed harvest rates with harvest rates established using perfect forecasts (i.e., observed total run) and the existing sliding-scale harvest rate formula. From 1980 to 2017, harvest rates exceeded the allowable harvest rate in 9 of 38 years (24% of years), but the harvest rates were 4.2% "too small", on average, assuming perfect management using the existing harvest control rule. In years when the harvest rates were too high, the exceedance harvest averaged 1,967 tons per year.

Based on these values, ADF&G harvest managers are managing the fishery to be close to the preseason guideline harvest levels, as described in policy set by the Board of Fisheries. In some years, harvests exceed the GHL, in part because managers are trying to meet that harvest level rather than trying stay below the GHL when the targeted exploitation rate is less than 20%. As noted above, the maximum allowable harvest rate (20%) was exceeded in 7 of 38 years, averaging 23.9% in these years. Herring forecasts should incorporate recent downward trends, as shown in recent years, as a means to avoid over forecasting herring biomass.

Sitka Tribal members and staff are concerned that the harvest guideline levels do not adequately consider the needs for subsistence and the ability of subsistence fishers to meet those needs. The aggressive harvest rate in Sitka Sound reduced the amount of herring that would otherwise spawn in areas of the subsistence fishery. The Board of Fisheries has expanded an area closed to commercial fishing as a means to reduce interactions with the subsistence users but subsistence users often do not meet their needs. Given that the commercial fishery often harvests herring adjacent to the closed area and subsistence fishers often fail to meet their need, the question remains as to whether the closed area is sufficiently large to minimize the effect of the commercial fishery on the subsistence fishery.

Herring Management in British Columbia

Management of herring stocks in BC is generally similar to management in Southeast Alaska, but the harvest threshold is based on the post-fishery (spawning) biomass rather than the total biomass as in Alaska. For example, the approach in Sitka Sound allows the spawning biomass to fall 12% below the harvest threshold (25,000 tons). Also, DFO scientists recently recommended a more conservative threshold level before allowing the commercial fishery to harvest herring (DFO 2017).

BC herring are currently managed as five major stocks and 2 minor stocks (Martell et al. 2012). Annual catch advice for each of these areas is based on current estimates of stock status, and a 20% exploitation rate if the post-fishery stock (spawning biomass) is above the threshold (cutoff) for the five major stocks and a 10% exploitation rate for the two minor stocks. Threshold levels for the five major stocks were historically based on the 1996 estimate of unfished biomass (**Bo)** and the assumption that a minimum spawning stock of 25% of the unfished population was sufficient to ensure long-term sustainability, based on previous simulation studies. Also, a threshold level of 25% of **Bo** is thought to be more conservative than the DFO default Limit Reference Point of $0.4\mathbf{B}_{MSY}$. According to Martell et al. (2012), $\mathbf{B}_{MSY}$ is normally in the range of 35% of the unfished biomass for many fish stocks; therefore, 40% of $\mathbf{B}_{MSY}$ is roughly 14% of unfished biomass which is significantly lower than 25% of **Bo** that is used for BC herring. Martel et al. (2012) note that surplus production in most fish stocks is usually maximized when the stock is depleted to ~30%-45% of its unfished state, i.e., an abundance that is 5% to 20% higher than the threshold value.

Martell et al. (2012) concluded that 20% is an appropriate exploitation rate for those major stock areas that are well above threshold levels based on 25% of the estimated unfished biomass (**Bo)**. The recommended 20% harvest rate is based on an analysis of stock dynamics which indicates this level will stabilize both catch and spawning biomass.

For the major stock areas, the harvest control rule combines both constant exploitation rate and constant escapement policies, allowing for smaller fisheries in areas where the 20% harvest rate would bring the escapement down to levels below the threshold. The BC herring harvest rule operates as follows:

- If the forecast run ($\mathbf{B}_{t+1}$) is less than the cutoff: the area is closed to all commercial harvest.
- If the forecast run ($\mathbf{B}_{t+1}$) is greater than the cutoff: a commercial harvest is permitted and the harvest rate is based on the following rules:
    A) If $0.8\mathbf{B}_{t+1}$ > Threshold, then harvest rate **u**= 20%.
    B) If $0.8\mathbf{B}_{t+1}$ < Threshold, then harvest rate $\mathbf{u} = (\mathbf{B}_{t+1} - \text{Threshold})/\mathbf{B}_{t+1}$