# STOCK ASSESSMENT AND MANAGEMENT ADVICE FOR BRITISH COLUMBIA PACIFIC HERRING: 2014 STATUS AND 2015 FORECAST

*Photo: Herring. Credit: DFO*

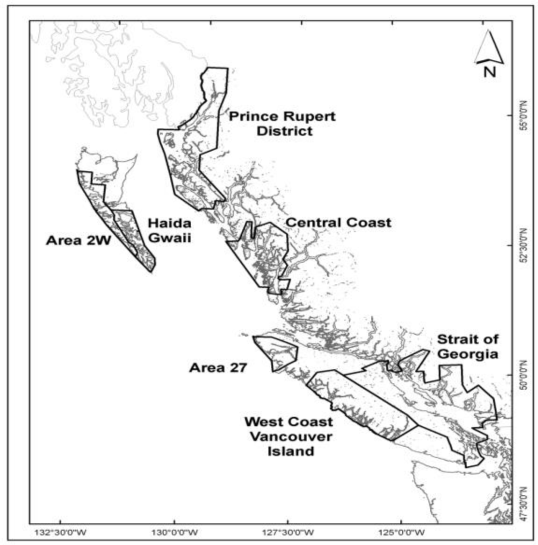


*Figure 1: British Columbia Pacific Herring major stock areas: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), West Coast of Vancouver Island (WCVI), and minor stock areas: Area 2W and Area 27.*

## Context:

*Pacific Herring (Clupea pallasi) is a pelagic species inhabiting inshore and offshore waters of the North Pacific. In the eastern Pacific, herring distribution ranges from California to the Beaufort Sea. Herring annually migrate between feeding and spawning areas. Fish mature and recruit to the spawning stock primarily between ages 2 and 5. In British Columbia (BC), herring predominantly recruit at age 3. BC herring stocks are managed based on five major and two minor stock areas. The five major BC herring stocks are Haida Gwaii (Area 2E), Prince Rupert District, Central Coast, Strait of Georgia, and West Coast of Vancouver Island, while the two minor herring stocks are Area 2W and Area 27 (Figure 1). Catch and survey information is collected independently for each of these seven areas and science advice is provided on the same scale.*

*Fisheries Management Branch annually requests science advice regarding the status of herring stocks in BC and harvest options. Advice was also requested this year on the impact of reducing survey frequency.*

*This Science Advisory Report is from the September 3-4, 2014 Stock Assessment and Management Advice for BC Pacific Herring: 2014 Status and 2015 Forecast. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada Science Advisory Schedule as they become available.*

## SUMMARY


- Commercial fishing for British Columbia (BC) Pacific Herring is managed as five major stock management areas: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG), and West Coast of Vancouver Island (WCVI), and two minor herring stock management areas: Haida Gwaii Area 2W, and WCVI Area 27 (Figure 1).
- The 2014 spawning biomass and forecast of the 2015 spawning biomass were assessed using an integrated statistical catch-at-age model (ISCAM or "the assessment model"). Advice for each Pacific Herring stock is presented in probabilistic decision tables showing predicted status in 2015 given a range of constant catches relative to target harvest rates and performance metrics relating directly to the existing herring harvest control rule.
- Assessment results and advice are summarized by management area. All herring biomass results are reported in metric tonnes (t). *SB* denotes spawning biomass. Stock status is measured relative to equilibrium unfished spawning biomass ($SB_0$). Estimates of various quantities are presented as the 5-95% credible interval, with median values in parentheses.
- There was concern that data from the Central Coast area survey resulted from an uncommonly high number of samples (6 of 13) that were collected from Statistical Area 8, which is historically an unfished area with consistently smaller (age 2) fish. As a result, Area 8 biological samples were weighted by their average relative contribution over the past 20 years (7%) in the analysis.
- On-ground observations by Nuu-chah-nulth fishers and Fisheries and Oceans Canada (DFO) staff felt that the spawning biomass in 2014 was much lower than estimated by the assessment model. In addition, it was determined that WCVI Statistical Area 24 samples were not representative and therefore removed from the analysis.
- Two sensitivity cases were conducted: one mimicking the historical management procedure without the Poor, Average, and Good recruitment categories (fixed cut-off and assumption of $q$=1); and, the second a preliminary evaluation of the consequences of reductions in fishery-independent survey data on historical estimates of stock size.
- The comparison of performance of the current (base) management procedure and the former management procedure (1995-2010) illustrated the former management procedure generated lower estimates of stock biomass and lower catches at predicted harvest rates. The historical management procedure produces lower estimates of spawning biomass for all major stocks, and higher depletion estimates ($SB_t / SB_0$) for all major stocks except for the Prince Rupert District. However, for any given catch level, the former management procedure shows there to be a higher probability of exceeding target harvest rates than for the base model.
- A ten year retrospective analysis of data for the Central Coast was conducted to examine potential implications of less frequent spawn survey data (biennial instead of annual) on historical estimates of stock size. Systematic under-estimation of spawning biomass was observed when biomass was increasing, and systematic over-estimation of spawning biomass was observed when biomass was decreasing, with catch rates exceeding the target harvest rate in the latter case. Retrospective errors can reverse abruptly as stock trends change, but the analysis could not include historical decisions that would have been made given less frequent spawn survey collections, and how the decisions would have affected the stock. However, it was agreed that the behaviour of this systematic over- and under-estimation was an undesirable property associated with less frequent surveys.

## Haida Gwaii (HG)

- All herring spawning from Cumshewa Inlet in the north to Louscoone Inlet in the south are assumed to be part of the Haida Gwaii stock.
- No commercial herring fishery occurred in this area from 2005 through 2014.
- Spawn index declined from 16,025 t in 2013 to 10,566 t in 2014 and the 2014 biological samples contain a high proportion of age 4 fish and few age 3 fish.
- The estimated spawning biomass in 2014 ($SB_{2014}$) is 11,912 – 43,875 t (median 22,993 t). $SB_{2014}$ is estimated to be 0.35 – 1.25 (median 0.67) of $SB_0$. The model estimates below average recruitment for 2013 and 2014.
- With low apparent recruitment entering the spawning population in 2014 and similar natural mortality estimates for recent years, the model estimates that the 2014 spawning stock biomass has declined from 2013.
- The projected spawning stock biomass in 2015, assuming no catch, is estimated to be 8,295 – 35,621 t (median 17,285 t), consisting of 5 – 31% (median 15%) age-3 fish and 46 – 86% (median 70%) age-4 and older fish.
- The median estimate of stock biomass is projected to decline in 2015 (relative to 2014), and, in the absence of fishing, the model estimates that there is a 5% probability the stock will be below the cut-off of 25% $SB_0$ in 2015.

## Prince Rupert District (PRD)

- All herring spawning in Statistical Areas 3 to 5 are assumed to belong to the Prince Rupert District stock.
- The combined total validated catch for the seine roe, the gillnet roe, and the food and bait fisheries was 2,003 t for the 2013/14 herring season. Commercial spawn-on-kelp operations also occurred in 2014.
- Spawn index declined from 25,755 t in 2013 to 17,125 t in 2014, and the 2014 biological samples contain a high proportion of age-4 fish and few age-3 fish.
- The estimated spawning biomass in 2014 ($SB_{2014}$) is 15,783 – 51,772 t (median 29,023 t). $SB_{2014}$ is estimated to be 0.23 - 0.84 (median 0.46) of $SB_0$. The model estimates below average recruitment for 2013 and 2014.
- With no apparent increase in recruitment entering the spawning population in 2014 and similar natural mortality estimates for recent years, the model estimates the 2014 spawning stock biomass to be similar to the 2013 level. Recent estimates of natural mortality are highly uncertain.
- The projected spawning stock biomass in 2015, assuming no catch, is estimated to be 13,550 – 48,310 t (median 25,770 t), consisting of 6 – 20% (median 11%) age-3 fish and 66 – 89% (median 80%) age-4 and older fish.
- The median estimate of stock biomass is projected to decline in 2015 (relative to 2014), and in the absence of fishing, there is a 12% probability the stock will be below the cut-off of 25% $SB_0$ in 2015.

## Central Coast (CC)

- All herring spawning in Kitasu Bay (a portion of Statistical Area 6), Statistical Area 7, and part of Statistical Area 8 (Kwakshua Channel and Fitzhugh Sound) are assumed to be part of the Central Coast stock.

- Commercial gillnet roe fishery caught 687 t in 2014. No commercial herring fishery occurred in this area from 2008 through 2013. Commercial spawn-on-kelp operations also occurred in 2014.
- Spawn index declined from 20,359 t in 2013 to 13,309 t in 2014. The 2013 observation was preceded by seven years of low spawn observations (similar to the late 1960s).
- The estimated spawning biomass in 2014 ($SB_{2014}$) is 14,894 – 42,791 t (median 25,384 t). $SB_{2014}$ is estimated to be 0.25 - 0.69 (median 0.42) of $SB_0$. The model estimates above average recruitment for 2010, 2012 and 2014.
- The 2014 stock assessment estimates an increase in median estimates of spawning biomass from 2012 to 2014, due in part to above average recruitment in 2010, 2012, and 2014, a high spawn index in 2013 (preceded by seven years with low index values), and apparent decreases in natural mortality.
- The projected spawning stock biomass in 2015, assuming no catch, is estimated to be 15,100 – 49,552 t (median 27,735 t), consisting of 34 – 58% (median 46%) age-3 fish and between 33 – 55% (median 44%) age-4 and older fish.
- The median estimate of stock biomass is projected to increase in 2015 (relative to 2014), and, in the absence of fishing, there is a 4% probability the stock will be below the cut-off of 25% $SB_0$ in 2015.

## Strait of Georgia (SOG)

- All herring spawning in Statistical Areas 14 to 19, 28 and 29 (excluding Section 293), and part of 13 (Herring Sections 132 and 135, Deepwater Bay area south) are assumed to belong to the Strait of Georgia herring stock.
- The combined total validated catch for the seine roe, gillnet roe, food and bait and special use fisheries was 20,307 t for the 2013/14 herring season.
- Spawn index was at near historic high levels in 2014, and the 2014 biological samples contained a high proportion of age-3 fish and similar proportions of fish ages 4-6.
- The estimated spawning biomass in 2014 ($SB_{2014}$) is 116,805 – 289,976 t (median 186,273 t). $SB_{2014}$ is estimated to be 0.84 – 1.96 (median 1.31) of $SB_0$. The model estimates average recruitment in 2012-2014.
- Median spawning biomass has increased since 2010 due in part to above average recruitment in 2010 and 2011 and apparent decreases in natural mortality.
- The projected spawning stock biomass in 2015, assuming no catch, is estimated to be 108,090 – 277,900 t (median 174,350 t), consisting of 22 – 36% (median 29%) age-3 fish and 53 – 70% (median: 62%) age-4 and older fish.
- The median estimate of stock biomass is projected to decline in 2015 (relative to 2014), and in the absence of fishing there is a 0.00% probability the stock will be below the cut-off of 25% $SB_0$ in 2015.

## West Coast Vancouver Island (WCVI)

- All herring spawning in Statistical Areas 23 to 25 are assumed to belong to the west coast of Vancouver Island herring stock.
- The WCVI stock has been closed to commercial fisheries from 2006 to 2011 and in 2013. A commercial harvest option was available in 2012, but was not pursued. Commercial fishing opportunities were not permitted in 2014 following an interlocutory injunction as a result of a federal court decision.

- Spawn index observations were at historically low levels between 2006 and 2008 and again in 2010 (ranging from 2,246 t to 2,875 t). Spawn index increased to 12,342 t in 2013 then to 13,901 in 2014. Biological sampling of the WCVI stock is characterized by extremely low sample sizes in 2013 (five samples) and 2014 (three samples). The 2014 biological samples contain a high proportion of age-3 fish.
- The estimated spawning biomass in 2014 ($SB_{2014}$) is 18,461 – 54,710 t (median 32,038 t). $SB_{2014}$ is estimated to be 0.33 – 0.90 (median 0.55) of $SB_0$. The model estimates below average recruitment in 2011 and 2012.
- Median spawning biomass has increased since 2008 from historically low levels, due in part to above average recruitment in 2010 and apparent decreases in natural mortality.
- The projected spawning stock biomass in 2015, assuming no catch, is estimated to be 17,549 – 56,103 t (median 31,505 t), consisting of 23 – 44% (median 33%) age-3 fish and 39 – 62% (median 52%) age-4 and older fish.
- The median estimate of stock biomass is projected to decline in 2015 (relative to 2014), and, in the absence of fishing, there is a 1% probability the stock will be below the cut-off of 25% $SB_0$ in 2015

## Area 2W

- All herring spawning in Statistical Area 2W (except Herring Section 006) are assumed to belong to this Haida Gwaii minor stock.
- A commercial spawn-on-kelp fishery occurred in this area in 2014.
- The estimated spawning biomass in 2014 ($SB_{2014}$) is 1,210 – 7,847 t (median 3,268 t). $SB_{2014}$ is estimated to be 0.39 – 2.17 (median 0.98) of $SB_0$. The model estimates above average recruitment in 2013.
- Median spawning biomass has declined since 2011, due in part to decreases in the spawn index and apparent increases in natural mortality.
- The projected spawning stock biomass in 2015, assuming no catch, is estimated to be 1,083 – 8,983 t (median 3,338 t), consisting of 1 – 22% (median 6%) age-3 fish and 71–98% (median 91%) age-4 and older fish.

## Area 27

- All herring spawning in Statistical Area 27 are assumed to belong to this West Coast of Vancouver Island minor stock.
- A commercial spawn-on-kelp fishery occurred in this area in 2014.
- The estimated spawning biomass in 2014 ($SB_{2014}$) is 740 – 2,509 t (median: 1,387 t). $SB_{2014}$ is estimated to be 0.37 – 1.11 (median 0.66) of $SB_0$. The model estimates below average recruitment in 2011-2013.
- Median spawning biomass has remained relatively constant over the past decade, while natural mortality may have decreased over the same period.
- The projected spawning stock biomass in 2015, assuming no catch, is 744 – 2,963 t (median 1,506 t), consisting of 12 – 61% (median 31%) age-3 fish and 31– 80% (median 58%) age-4 and older fish. There is high uncertainty in the estimates of the number of age-3 fish in 2015.

# INTRODUCTION

Pacific Herring (*Clupea pallasi*) is a pelagic species migrating between inshore spawning and offshore feeding areas of the North Pacific Ocean. Herring distribution in the eastern Pacific Ocean ranges from California to the Beaufort Sea. Pacific Herring mature and recruit to the spawning stock predominantly at age-3 within British Columbia (BC), but age-at-recruitment tends to increase with latitude within this range.

Pacific Herring in BC are divided into five major and two minor stocks for evaluation and management (Figure 1). This stock structure is supported in part by the results of multi-year tagging and genetic studies (Hourston 1982, Beacham et al. 2008, Flostrand et al. 2009). The major stocks are: Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), Strait of Georgia (SOG) and West Coast of Vancouver Island (WCVI). The two minor herring stocks are Area 2W (on the west coast of Haida Gwaii) and Area 27 (on the west coast of Vancouver Island, centered on Quatsino Sound).

Pacific Herring in BC have been harvested for many years to provide a variety of food products. First Nations have traditionally harvested whole herring and herring spawn-on-kelp for food, social and ceremonial purposes. Pacific Herring were commercially harvested and processed (reduced) into relatively low-value products such as fishmeal and oil from the early 1930s through the late 1960s. Commercial catches increased dramatically in the early 1960s, but were unsustainable. By 1965, most of the older fish had been removed from the spawning population by overfishing and sequential weak year-classes, attributed to a combination of unfavourable environmental conditions and low spawning biomass. The commercial fishery collapsed and was closed by the federal government in 1967. During the closure period limited fishing activity occurred at low levels from 1967-1971 (Hourston 1980). Growing interest in harvesting roe herring for export to Japan resulted in a small experimental roe harvest, beginning in 1971. The roe fishery expanded rapidly until 1983, when a fixed harvest rate was introduced to regulate catch. A series of above average year-classes in the early 1970s led to rapid rebuilding of Pacific stocks and the re-opening of areas for commercial fishing.

At present, the Pacific Herring fisheries in BC consists of: commercial fishing opportunities for food and bait herring, spawn-on-kelp products, and roe herring; First Nations food, social, and ceremonial fisheries (FSC); and, recreational opportunities. Combined commercial removals for 2008 to 2014 from the roe, food and bait, and special use fisheries operating in the five major and two minor BC Herring stock assessment areas are shown in Table 1.

*Table 1. Combined commercial removals (tonnes) from roe, and food and bait and special use fisheries operating in the BC herring stock assessment areas from 2008 to 2014. Spawn-on-kelp fishery removals are not included in this table.*

| Stock Area | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|
| Haida Gwaii | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Prince Rupert District | 1,662 | 2,000 | 1,484 | 2,147 | 1,383 | 2,027 | 2,003 |
| Central Coast | 0 | 0 | 0 | 0 | 0 | 0 | 687 |
| Strait of Georgia | 9,934 | 10,170 | 8,324 | 5,128 | 11,339 | 16,566 | 20,307 |
| West Coast Vancouver Island | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Area 2W | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Area 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Management of BC Pacific Herring stocks has historically been directed by a Management Framework based on science advice initially approved in 1986, and further refined in 1996, for five major and two minor stock areas in BC. The framework established a commercial fishery cut-off at 25% of the estimated unfished spawning biomass ($SB_0$) for each major stock assessment area. A 20% harvest rate was applied to the forecasted pre-fishery stock biomass that exceeded the cut-off. The minor herring stocks (Areas 2W and 27) were not subject to a commercial fishery cut-off; instead, a 10% harvest rate was applied.

The harvest control rule (HCR) was based in part on analyses conducted on the SOG stock in the mid to late 1980s, with a goal of keeping stocks above cut-off levels. Contrary to the predictions of the analyses done in the late 1980s, some herring stocks appear to have been below cut-off levels relatively frequently. Since 1986, there have been several different stock assessments models used, each of which had different assumptions and new data, so that for each assessment, in each year, there were new estimates of current and unfished spawning biomass levels. It is therefore not possible to compare the current stock assessments estimates to what would have been estimated historically. Accordingly, the best approximation that is available to determine if stocks were above or below cut-offs is to examine historical Integrated Fisheries Management Plans. On the basis of this analysis, three of the major herring stocks, WCVI, CC, and HG, were below cut-off for 32%, 21%, and 46% of years, respectively, from 1986-2013. The relative contribution of harvest, environmental/ecological interactions causing changes in natural mortality and growth, or alternative assessment models (in particular more conservative models applied before 2011), and/or other factors to the stocks having been estimated to be below cut-offs is currently not well understood.

DFO's Fisheries Management Branch requested advice on the following:

- present trends in herring biomass in BC;
- an assessment of the current status of Pacific Herring for each of the five major and two minor stocks relative to estimates of unfished equilibrium spawning biomass ($SB_0$); and,
- projections of the consequences of different total allowable catch levels against probabilistic harvest and spawning biomass metrics to account for uncertainty in the advice.
- an examination of the potential implications of less frequently conducting spawn surveys (biennial instead of annual) on historical estimates of stock size.

# ASSESSMENT

## Stock Assessment Modeling for 2014

The integrated statistical catch-at-age model (ISCAM) was reviewed and approved in 2011 for the estimation of herring spawning stock biomass. (Martell et al., 2012, and has since been used for the provision of science advice from 2011 to 2014. This combined-sex, catch-at-age model was applied independently to each stock area and tuned to fishery-independent spawn index data, annual estimates of commercial catch since 1951, and age composition data from the commercial fishery and the test fishery charter program. The key results from stock assessments of Pacific Herring in five major and two minor stock areas are summarized as stock reconstructions, status of spawning stock in 2014, and projected spawning biomass in 2015.

The ISCAM model estimated stock-recruitment parameters (recruitment is modelled as age-2 fish, while recruitment to the spawning biomass occurs at age-3), time-varying natural mortality, catchability coefficients for the survey time series, and selectivity parameters for the commercial fishery, and those survey series for which age data were available. One-year projections for 2015 were performed for each major and minor stock area, over a range of constant catches, to estimate probabilities that spawning biomass and harvest rate metrics were below and above control points, respectively, as specified in the herring HCR. All projections were generated from posterior distributions developed from a Bayesian Markov Chain Monte Carlo (MCMC) search to quantify the uncertainty associated with parameter estimation. Estimates of various quantities were calculated from these samples, and are presented as the 5-95% credible interval with median values in parentheses. Two sensitivity cases: application of the historical management procedure (fixed cutoff and assumption of $q$=1), and a preliminary evaluation of the consequences of reductions in fishery-independent survey data were also conducted. Adjustments made in analytical procedures included weighting Area 8 biological samples by their average relative contribution over the past 20 years (7%), due to concerns that data acquired and used for the Central Coast area resulted from an uncommonly high number of samples (6 of 13) that were collected from Statistical Area 8 (which is historically an unfished area with consistently smaller (age 2) fish), and, removing WCVI Statistical Area 24 samples, because it was determined that they were not representative.

Advice to managers on estimated (current) spawning biomass, $SB_{2014}$, estimated unfished equilibrium spawning biomass ($SB_0$), estimated ratio $SB_{2014}/SB_0$, trends in age-2 recruitment and instantaneous natural mortality is presented in Figures 2 through 8. Tables 2 and 3 give estimates of spawning biomass in recent years ($SB_t$), $SB_0$, 0.25 $SB_0$, and the ratio $SB_{2014}/SB_0$. Figure summaries include references to years of above (or below) average recruitment, indicating years where recruitment was high or low relative to predictions from the Beverton-Holt stock recruitment relationship.

*Table 2. Median estimates (with 5-95% credible interval) of spawning biomass (SBt) for BC herring stocks, 2009-2014.*

| Stock Area | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|
| HG | 11,862<br>(7,826-18,138) | 12,217<br>(7,970-18,823) | 13,421<br>(8,532-20,571) | 21,030<br>(13,309-32,386) | 31,448<br>(19,531-51,259) | 22,993<br>(11,912-43,875) |
| PRD | 17,766<br>(12,568-25,225) | 19,884<br>(13,771-28,725) | 22,053<br>(14,740-32,422) | 23,437<br>(15,495-35,164) | 29,732<br>(18,736-47,180) | 29,023<br>(15,783-51,772) |
| CC | 15,273<br>(10,617-22,501) | 15,715<br>(10,986-23,087) | 15,040<br>(10,450-22,077) | 14,363<br>(10,019-21,142) | 23,476<br>(15,616-35,962) | 25,384<br>(14,894-42,791) |
| SOG | 71,658<br>(53,209-107,642) | 66,525<br>(49,366-100,706) | 109,415<br>(81,031-161,907) | 131,141<br>(97,030-187,999) | 147,686<br>(103,847-214,104) | 186,273<br>(116,805-289,976) |
| WCVI | 8,364<br>(5,554-12,680) | 10,352<br>(6,759-15,662) | 14,149<br>(9,314-21,499) | 15,263<br>(10,163-23,155) | 20,051<br>(13,307-31,107) | 32,038<br>(18,461-54,710) |
| Area 2W | 2,840<br>(1,667-4,746) | 3,519<br>(2,049-5,955) | 3,844<br>(2,225-6,664) | 3,846<br>(2,136-6,919) | 3,738<br>(1,824-7,444) | 3,268<br>(1,210-7,847) |
| Area 27 | 1,590<br>(1,041-2,473) | 1,417<br>(922-2,229) | 1,314<br>(844-2,088) | 1,192<br>(763-1,918) | 1,318<br>(785-2,214) | 1,387<br>(740-2,509) |

*Table 3. Median estimates (with 5-95% credible interval) of 2014 spawning biomass ($SB_{2014}$), unfished spawning biomass ($SB_0$), 0.25 $SB_0$, and the ratio $SB_{2014}$/ $SB_0$ for all BC herring stocks.*

| | Spawning Biomass (SB2014) | | | Unfished Biomass (SB $B_0$) | | | 0.25*$SB_0$ | | | Median ratio of spawning biomass to unfished equilibrium spawning biomass (SB2014/$SB_0$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stock | 5th percentile | Median | 95th percentile | 5th percentile | Median | 95th percentile | 5th percentile | Median | 95th percentile | 5th percentile | Median | 95th percentile |
| HG | 11,912 | 22,993 | 43,875 | 25,730 | 33,964 | 46,862 | 6,433 | 8,491 | 11,716 | 0.35 | 0.67 | 1.25 |
| PRD | 15,783 | 29,023 | 51,772 | 48,109 | 61,797 | 87,321 | 12,027 | 15,449 | 21,830 | 0.23 | 0.46 | 0.84 |
| CC | 14,894 | 25,384 | 42,791 | 48,199 | 60,233 | 78,930 | 12,050 | 15,058 | 19,732 | 0.25 | 0.42 | 0.69 |
| SOG | 116,805 | 186,273 | 289,976 | 115,140 | 141,757 | 182,932 | 28,785 | 35,439 | 45,733 | 0.84 | 1.31 | 1.96 |
| WCVI | 18,461 | 32,038 | 54,710 | 46,651 | 57,744 | 72,933 | 11,663 | 14,436 | 18,233 | 0.33 | 0.55 | 0.90 |
| Area 2W | 1,201 | 3,268 | 7,847 | 2,008 | 3,291 | 6,028 | 502 | 823 | 1,507 | 0.39 | 0.98 | 2.17 |
| Area 27 | 740 | 1,387 | 2,509 | 1,457 | 2,089 | 3,162 | 364 | 522 | 791 | 0.37 | 0.66 | 1.11 |

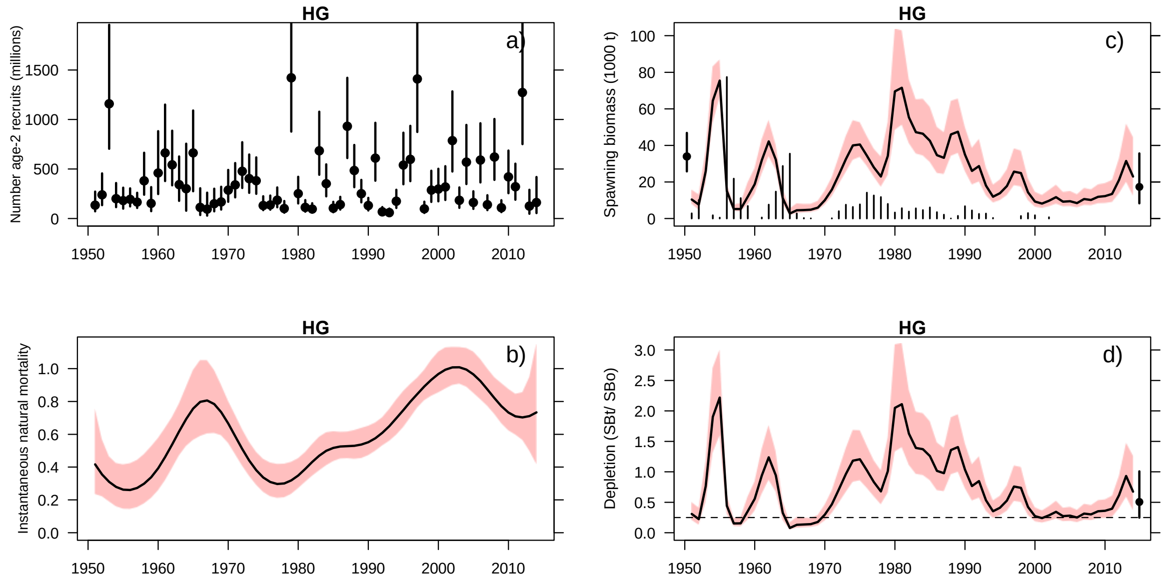


*Figure 2. Summary of the dynamics of the HG stock from 1951 to 2014, where solid circles with vertical lines, and solid lines with surrounding pink envelopes, represent medians and 5-95% credible intervals. Upper left panel (a) shows the reconstruction of number of age-2 recruits. (millions); Lower left panel (b) shows the reconstruction of instantaneous natural mortality; Upper right panel (c) shows the reconstruction of spawning biomass ($SB_t$) for each year t, with unfished values shown at far left (solid circle and vertical lines) and the projected spawning biomass given zero catch ($SB_{2015}$) shown at the far right (solid circle and vertical lines). Time series of thin vertical lines denote commercial catch (excluding commercial SOK); Lower right panel (d) shows the median ratio ($SB_t/SB_0$) of spawning biomass to unfished equilibrium spawning biomass with projected depletion shown at the far right (solid circle and vertical lines). Dashed horizontal line denotes 0.25 $SB_0$.*

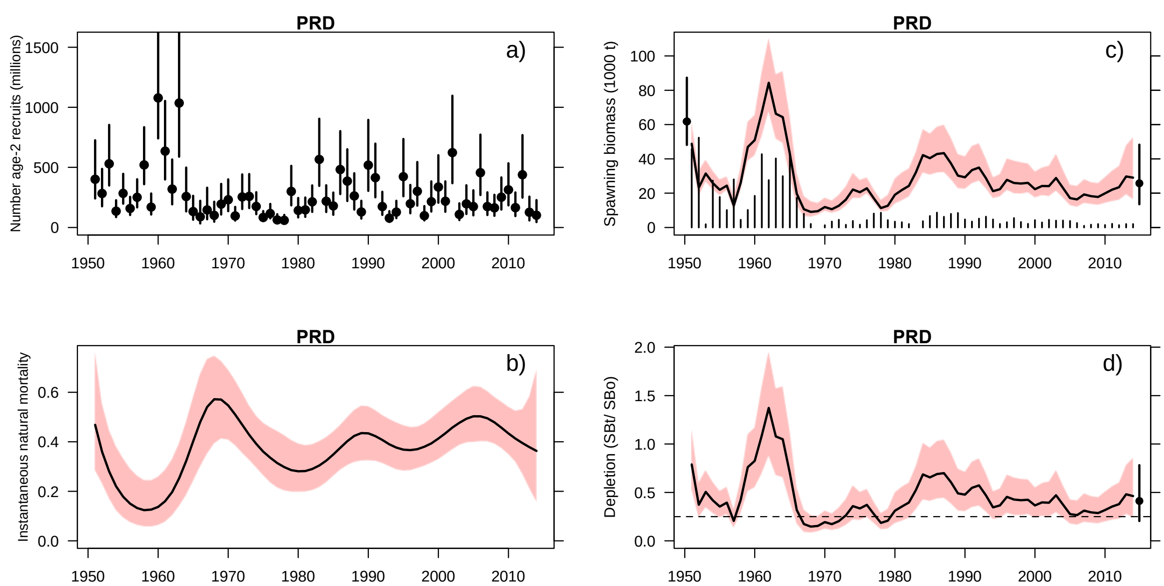


*Figure 3. Summary of the dynamics of the PRD stock from 1951 to 2014. See Figure 2 for detailed description.*

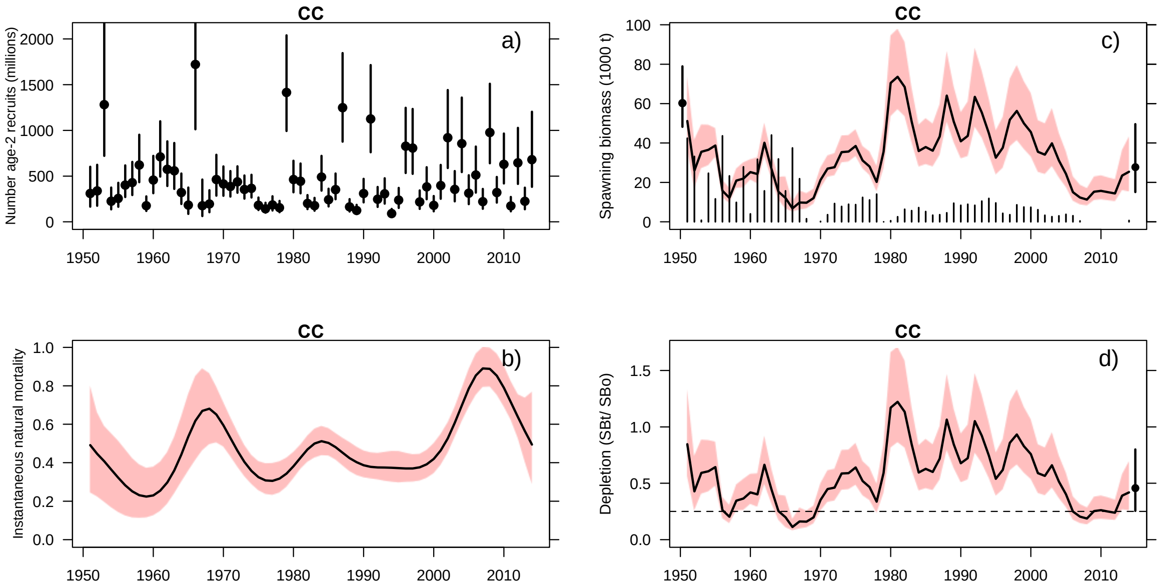


*Figure 4. Summary of the dynamics of the CC stock from 1951 to 2014. See Figure 2 for detailed description.*

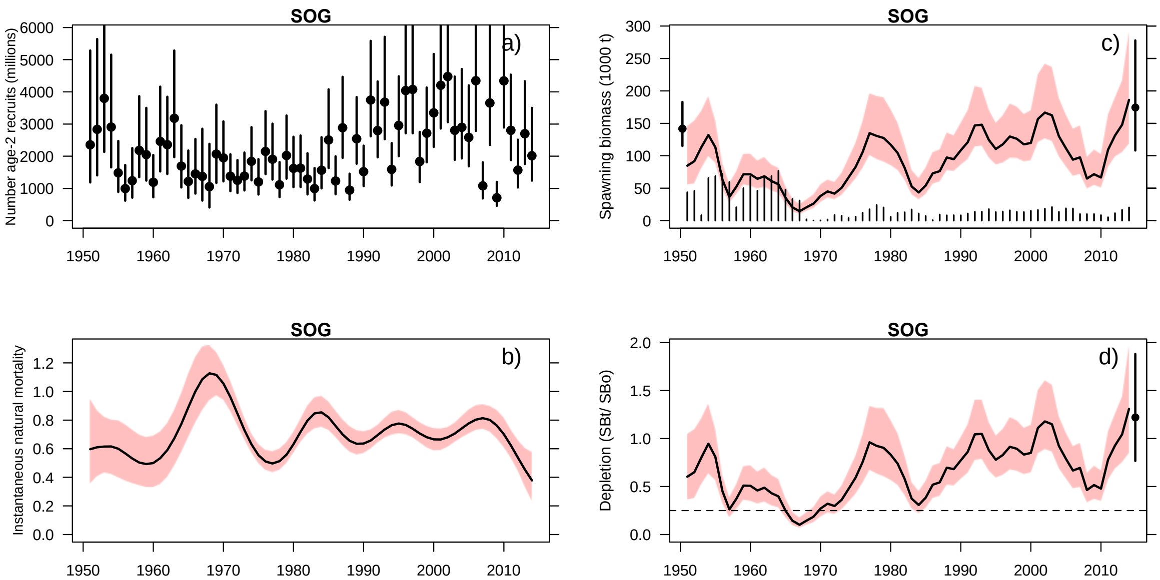


*Figure 5. Summary of the dynamics of the SOG stock from 1951 to 2014. See Figure 2 for detailed description.*

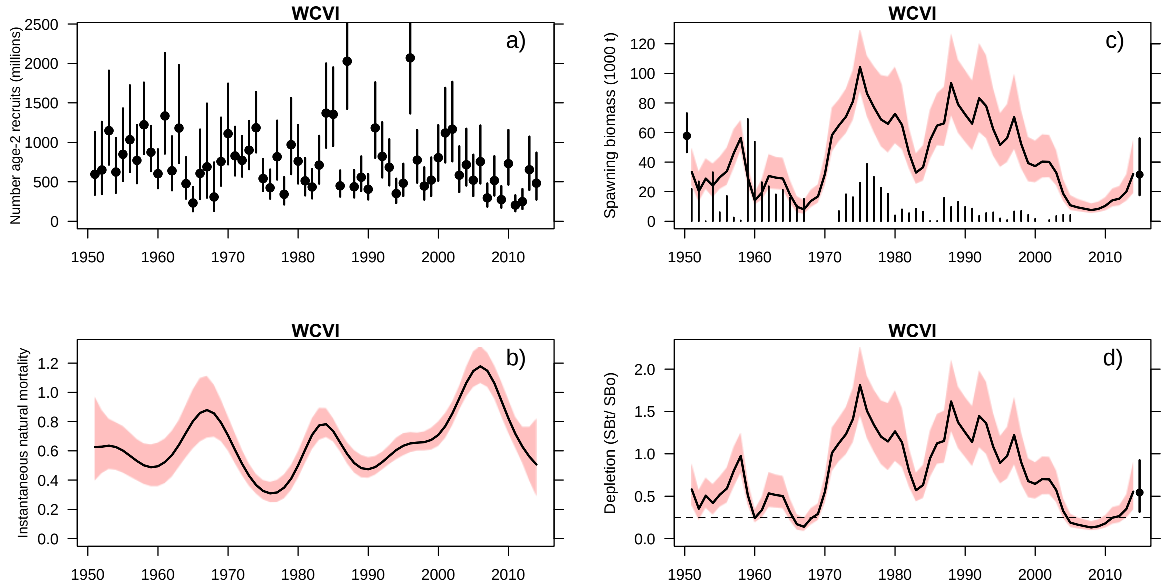


*Figure 6. Summary of the dynamics of the WCVI stock from 1951 to 2014. See Figure 2 for detailed description.*

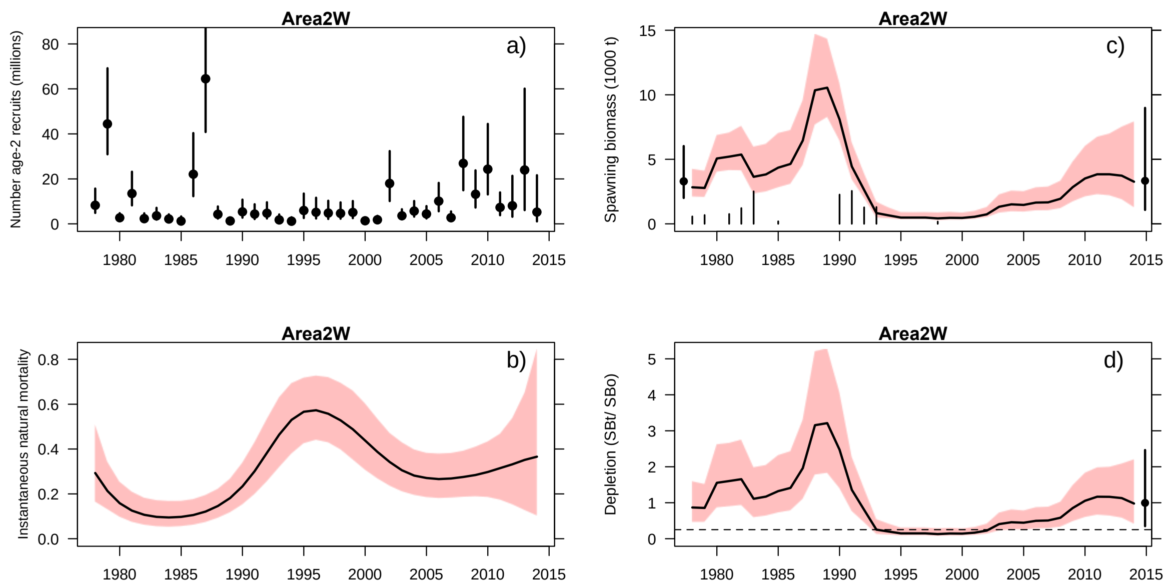


*Figure 7. Summary of the dynamics of the Area 2W stock from 1951 to 2014. See Figure 2 for detailed description.*

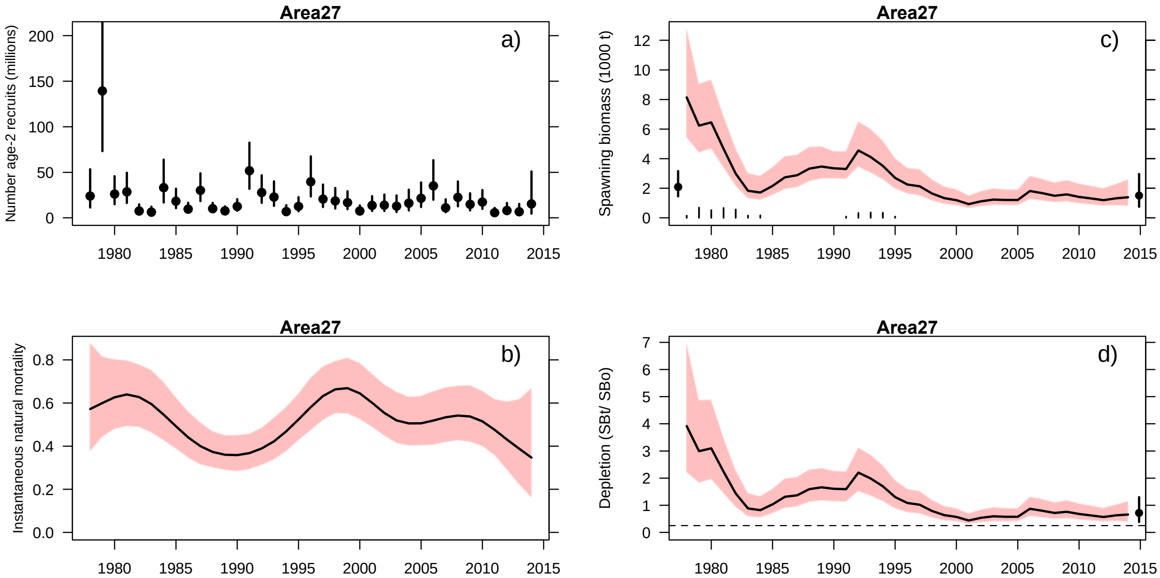


*Figure 8. Summary of the dynamics of the Area 27 stock from 1951 to 2014. See Figure 2 for detailed description.*

# Projection Results and Decision Tables

Projected spawning biomasses assuming zero catch in 2015 and the relative contribution of fish of age-3 and ages 4-10 are presented in Table 4. Advice to managers for 2015 for the major stock areas is presented as a set of decision tables that provide probabilities of the projected spawning biomass in 2015 ($SB_{2015}$) falling below the 0.25 $SB_0$ level, and of the harvest rate exceeding the 20% and 10% target rates for a range of constant catch levels (Table 5). Decision tables for minor stock areas provide probabilities of the harvest rate exceeding the 10% target rate for a range of constant catch levels (Table 5). Decision tables comparing the performance of the base case with the historic management procedure were also calculated.

Projections of spawning biomass in 2015 ($SB_{2015}$) were made over a range of yield options from 0 t to a maximum, well above recent catch, in increments that vary depending on the productivity of the stock. Note that catches are held constant, so there is no reduction of the catch in the projections if $SB_{2015}$ is less than 0.25 $SB_0$.

As an example of how to read the tables for the five major stock areas (HG, PRD, CC, SOG, WCVI): given a catch of 1,000 t from the Haida Gwaii stock, the estimated probability that the harvest rate ($U'$) exceeds the 20% target rate is 0.002 (0.2%), the ratio of $SB_{2015}$/0.25 $SB_0$ value is 1.94 and the probability that $SB_{2015}$ < 0.25 $SB_0$ is estimated to be 0.07 (7%).

The decision tables for the minor stocks (Area 2W, Area 27) do not include biomass performance metrics, because biomass metrics were not historically used. For example, given a catch of 200 t in Area 2W, the estimated harvest rate in 2015 (Med $U'_{2015}$) is 0.06 (6%) and the probability that $U'_{2015}$ > 10% is estimated to be 0.20 (20%).

*Table 4. Estimates of projected spawning biomass in 2015 given zero catch, and predicted proportions of fish of age-3 and of ages 4-10 for all BC herring stocks.*

| | Projected proportion age-3 fish in 2015 | | | Projected proportion ages 4-10 fish in 2015 | | | Projected spawning biomass (*$SB_{2015}$*) given zero catch | | |
|---|---|---|---|---|---|---|---|---|---|
| Stock | 5th percentile | Median | 95th percentile | 5th percentile | Median | 95th percentile | 5th percentile | Median | 95th percentile |
| HG | 0.05 | 0.15 | 0.31 | 0.46 | 0.70 | 0.86 | 8,295 | 17,285 | 35,621 |
| PRD | 0.06 | 0.11 | 0.20 | 0.66 | 0.80 | 0.89 | 13,550 | 25,770 | 48,310 |
| CC | 0.34 | 0.46 | 0.58 | 0.33 | 0.44 | 0.55 | 15,100 | 27,735 | 49,552 |
| SOG | 0.22 | 0.29 | 0.36 | 0.53 | 0.62 | 0.70 | 108,090 | 174,350 | 277,900 |
| WCVI | 0.23 | 0.33 | 0.44 | 0.39 | 0.52 | 0.62 | 17,549 | 31,505 | 56,103 |
| Area 2W | 0.01 | 0.06 | 0.22 | 0.71 | 0.91 | 0.98 | 1,083 | 3,338 | 8,983 |
| Area 27 | 0.12 | 0.31 | 0.61 | 0.31 | 0.58 | 0.80 | 744 | 1,506 | 2,963 |

*Table 5. Decision tables concerning the harvest and biomass metrics drawn from the herring harvest control rule for projected spawning biomass in 2015, given a range of constant annual catch strategies (in tonnes) for major stock areas HG, PRD, CC, SOG, and WCVI. Decision tables for minor stock areas (Area 2W, Area 27) show harvest metrics only because biomass metrics were not historically used. Values are the probabilities, under each annual catch strategy, of the spawning biomass in 2015 ($SB_{2015}$) being lower than 0.25 $SB_0$, and of the harvest rate being greater than 20% or 10%. The probabilities are the proportion of the MCMC samples for which the given criteria hold. One-year projections for HG, PRD, CC and WCVI use catch allocation ratios for each of the three fisheries (food and bait/ special use, seine roe and gillnet roe) based on 20-year historic average catches. The allocation ratio for SOG assumes a 50% allocation of TAC to the food and bait/ special use fisheries, 30% to seine roe, and 20% to gillnet roe.*

| | Biomass metrics | | Harvest metrics | Harvest metrics | |
|---|---|---|---|---|---|
| | BASE | BASE | BASE | BASE | BASE |
| TAC | Prob (below 0.25 $SB_0$ in 2015) | Median ratio of forecast biomass to 0.25 $SB_0$ | Prob (removal rate > target HR) | Prob (removal rate > target HR) | Median removal rate |
| (metric tonnes) | $P(SB_{2015} < 0.25\ SB_0)$ | $Med(SB_{2015} / 0.25\ SB_0)$ | P(U'2015 > 20%) | P(U'2015 > 10%) | Med (U'2015) |
| **HG** | | | | | |
| 0 | 0.05 | 2.02 | 0 | 0 | 0 |
| 1,000 | 0.07 | 1.94 | 0.002 | 0.10 | 0.06 |
| 1,325 | 0.08 | 1.92 | 0.01 | 0.25 | 0.07 |
| 1,500 | 0.08 | 1.91 | 0.02 | 0.34 | 0.08 |
| 1,800 | 0.09 | 1.88 | 0.05 | 0.50 | 0.10 |
| 2,000 | 0.09 | 1.86 | 0.08 | 0.60 | 0.11 |
| 2,100 | 0.10 | 1.86 | 0.10 | 0.64 | 0.12 |
| 2,750 | 0.11 | 1.81 | 0.25 | 0.85 | 0.15 |
| 3,000 | 0.12 | 1.79 | 0.31 | 0.89 | 0.16 |
| 3,725 | 0.14 | 1.74 | 0.50 | 0.95 | 0.20 |
| 4,000 | 0.15 | 1.72 | 0.57 | 0.97 | 0.21 |
| 5,000 | 0.18 | 1.65 | 0.76 | 0.99 | 0.26 |

| | Biomass metrics | | Harvest metrics | Harvest metrics | |
|---|---|---|---|---|---|
| | BASE | BASE | BASE | BASE | BASE |
| TAC | Prob (below 0.25 $SB_0$ in 2015) | Median ratio of forecast biomass to 0.25 $SB_0$ | Prob (removal rate > target HR) | Prob (removal rate > target HR) | Median removal rate |
| (metric tonnes) | $P(SB_{2015} < 0.25 SB_0)$ | $Med(SB_{2015} / 0.25 SB_0)$ | P(U'2015 > 20%) | P(U'2015 > 10%) | Med (U'2015) |
| 6,000 | 0.21 | 1.57 | 0.87 | 1.00 | 0.31 |
| 7,000 | 0.24 | 1.50 | 0.93 | 1.00 | 0.35 |
| 8,000 | 0.28 | 1.43 | 0.96 | 1.00 | 0.40 |
| **PRD** | | | | | |
| 0 | 0.12 | 1.65 | 0 | 0 | 0 |
| 1,600 | 0.16 | 1.57 | 0.00 | 0.10 | 0.06 |
| 2,000 | 0.17 | 1.54 | 0.01 | 0.25 | 0.08 |
| 2,640 | 0.19 | 1.51 | 0.03 | 0.50 | 0.10 |
| 3,000 | 0.20 | 1.49 | 0.07 | 0.63 | 0.11 |
| 3,250 | 0.20 | 1.48 | 0.10 | 0.70 | 0.12 |
| 4,000 | 0.23 | 1.44 | 0.23 | 0.86 | 0.15 |
| 4,100 | 0.23 | 1.44 | 0.25 | 0.87 | 0.15 |
| 5,000 | 0.26 | 1.39 | 0.42 | 0.95 | 0.19 |
| 5,350 | 0.27 | 1.38 | 0.50 | 0.97 | 0.20 |
| 6,000 | 0.29 | 1.34 | 0.61 | 0.99 | 0.22 |
| 8,000 | 0.35 | 1.24 | 0.85 | 1.00 | 0.29 |
| 10,000 | 0.42 | 1.14 | 0.95 | 1.00 | 0.36 |
| **CC** | | | | | |
| 0 | 0.04 | 1.83 | 0 | 0 | 0 |
| 1,000 | 0.06 | 1.78 | 0 | 0.002 | 0.04 |
| 1,780 | 0.07 | 1.75 | 0 | 0.10 | 0.06 |
| 2,000 | 0.07 | 1.74 | 0.001 | 0.16 | 0.07 |
| 2,225 | 0.07 | 1.73 | 0.003 | 0.25 | 0.08 |
| 2,860 | 0.08 | 1.70 | 0.02 | 0.50 | 0.10 |
| 3,000 | 0.09 | 1.69 | 0.03 | 0.55 | 0.10 |
| 3,700 | 0.10 | 1.66 | 0.10 | 0.76 | 0.13 |
| 4,000 | 0.11 | 1.65 | 0.14 | 0.82 | 0.14 |
| 4,650 | 0.12 | 1.62 | 0.25 | 0.92 | 0.16 |
| 5,000 | 0.12 | 1.60 | 0.32 | 0.94 | 0.17 |
| 5,920 | 0.14 | 1.56 | 0.50 | 0.98 | 0.20 |
| 6,000 | 0.14 | 1.56 | 0.51 | 0.98 | 0.20 |
| 8,000 | 0.19 | 1.47 | 0.80 | 1.00 | 0.26 |
| 10,000 | 0.23 | 1.39 | 0.93 | 1.00 | 0.32 |
| **SOG** | | | | | |
| 0 | 0.00 | 4.88 | 0 | 0 | 0 |
| 10,000 | 0.00 | 4.68 | 0 | 0.02 | 0.06 |

| | Biomass metrics | | Harvest metrics | Harvest metrics | |
|---|---|---|---|---|---|
| | BASE | BASE | BASE | BASE | BASE |
| TAC | Prob (below 0.25 $SB_0$ in 2015) | Median ratio of forecast biomass to 0.25 $SB_0$ | Prob (removal rate > target HR) | Prob (removal rate > target HR) | Median removal rate |
| (metric tonnes) | $P(SB_{2015} < 0.25 SB_0)$ | $Med(SB_{2015} / 0.25 SB_0)$ | P(U'2015 > 20%) | P(U'2015 > 10%) | Med (U'2015) |
| 12,500 | 0.00 | 4.63 | 0 | 0.10 | 0.07 |
| 14,900 | 0.00 | 4.58 | 0.001 | 0.25 | 0.08 |
| 17,850 | 0.00 | 4.52 | 0.01 | 0.49 | 0.10 |
| 20,000 | 0.00 | 4.48 | 0.02 | 0.65 | 0.11 |
| 25,000 | 0.00 | 4.38 | 0.09 | 0.88 | 0.14 |
| 25,500 | 0.00 | 4.37 | 0.10 | 0.89 | 0.14 |
| 30,000 | 0.00 | 4.28 | 0.23 | 0.97 | 0.16 |
| 30,600 | 0.00 | 4.27 | 0.25 | 0.97 | 0.17 |
| 36,750 | 0.00 | 4.14 | 0.49 | 1.00 | 0.20 |
| 36,800 | 0.00 | 4.14 | 0.50 | 1.00 | 0.20 |
| 40,000 | 0.00 | 4.08 | 0.61 | 1.00 | 0.22 |
| 50,000 | 0.00 | 3.88 | 0.85 | 1.00 | 0.27 |
| 60,000 | 0.00 | 3.69 | 0.96 | 1.00 | 0.31 |
| **WCVI** | | | | | |
| 0 | 0.010 | 2.18 | 0 | 0 | 0 |
| 2,000 | 0.018 | 2.08 | 0.00 | 0.09 | 0.06 |
| 2,055 | 0.019 | 2.08 | 0.00 | 0.10 | 0.06 |
| 2,550 | 0.022 | 2.06 | 0.00 | 0.25 | 0.08 |
| 3,000 | 0.025 | 2.03 | 0.01 | 0.41 | 0.09 |
| 3,250 | 0.026 | 2.02 | 0.02 | 0.50 | 0.10 |
| 4,000 | 0.031 | 1.99 | 0.07 | 0.73 | 0.12 |
| 4,300 | 0.033 | 1.98 | 0.10 | 0.79 | 0.13 |
| 5,000 | 0.039 | 1.94 | 0.20 | 0.89 | 0.15 |
| 5,300 | 0.040 | 1.93 | 0.25 | 0.92 | 0.16 |
| 6,000 | 0.050 | 1.90 | 0.37 | 0.96 | 0.18 |
| 6,750 | 0.058 | 1.86 | 0.50 | 0.98 | 0.20 |
| 8,000 | 0.075 | 1.81 | 0.69 | 0.99 | 0.23 |
| 10,000 | 0.107 | 1.72 | 0.88 | 1.00 | 0.29 |
| **Area 2W** | | | | | |
| 0 | - | - | - | 0 | 0 |
| 200 | - | - | - | 0.20 | 0.06 |
| 300 | - | - | - | 0.42 | 0.09 |
| 400 | - | - | - | 0.61 | 0.12 |
| 500 | - | - | - | 0.74 | 0.15 |
| 600 | - | - | - | 0.82 | 0.17 |
| 700 | - | - | - | 0.88 | 0.20 |

| | Biomass metrics | | Harvest metrics | Harvest metrics | |
|---|---|---|---|---|---|
| | BASE | BASE | BASE | BASE | BASE |
| TAC | Prob (below 0.25 $SB_0$ in 2015) | Median ratio of forecast biomass to 0.25 $SB_0$ | Prob (removal rate > target HR) | Prob (removal rate > target HR) | Median removal rate |
| (metric tonnes) | $P(SB_{2015} < 0.25 SB_0)$ | $Med (SB_{2015} / 0.25 SB_0)$ | P(U'2015 > 20%) | P(U'2015 > 10%) | Med (U'2015) |
| 800 | - | - | - | 0.92 | 0.23 |
| **Area 27** | | | | | |
| 0 | - | - | - | 0 | 0 |
| 50 | - | - | - | 0.00 | 0.03 |
| 100 | - | - | - | 0.16 | 0.07 |
| 105 | - | - | - | 0.19 | 0.07 |
| 110 | - | - | - | 0.22 | 0.07 |
| 115 | - | - | - | 0.25 | 0.08 |
| 200 | - | - | - | 0.73 | 0.13 |
| 250 | - | - | - | 0.88 | 0.16 |
| 750 | - | - | - | 1.00 | 0.43 |

## Sensitivity Modeling

Two sensitivity cases were conducted: one mimicking the historical management procedure without the Poor, Average, and Good recruitment categories (fixed cut-off and assumption of $q$=1); and, the second being a preliminary evaluation of the consequences of reductions in fishery-independent survey data on historical estimates of stock size.

The comparison of performance of the current (base) management procedure and the former management procedure (1995-2010) illustrated that the former management procedure generated lower estimates of stock biomass and lower catches at predicted harvest rates. The historical management procedure produces lower estimates of spawning biomass for all major stocks, and higher depletion estimates ($SB_t / SB_0$) for all major stocks except for the Prince Rupert District. However, for any given catch level, the former management procedure shows there to be a higher probability of exceeding target harvest rates than for the base model.

A ten year retrospective analysis of data for the Central Coast was conducted to examine potential implications of less frequent spawn survey data (biennial instead of annual) on historical estimates of stock size. Systematic under-estimation of spawning biomass was observed when biomass was increasing, and systematic over-estimation of spawning biomass was observed when biomass was decreasing, with catch rates exceeding the target harvest rate in the latter case. Retrospective errors can reverse abruptly as stock trends change, but the analysis could not include historical decisions that would have been made given less frequent spawn survey collections, and how the decisions would have affected the stock. However, it was agreed that the behaviour of this systematic over- and under-estimation was an undesirable property associated with less frequent surveys.

## Sources of Uncertainties

Recruitment and natural mortality are considered to be the most important processes determining the productivity of BC Pacific Herring stocks. Factors driving age-3 recruitment to the spawning biomass, forecasted by the assessment model, are not fully understood. Median (model) estimates of instantaneous natural mortality ($M$) appear to be decreasing in all of the major and minor stock areas, except HG and Area 2W. The reasons for these changes are not clear at present, but are under investigation as natural mortality is an important parameter in the stock assessment model because it affects current stock biomass and also the estimate of the unfished biomass. Long term declines in body size (weight at age) have been observed for all BC herring stocks and some Alaska herring stocks, from the early 1980s-2010. There has been a levelling off at the low end of the range in most recent year(s); however, factors causing these changes are poorly understood. Because of the uncertainty in $M$, stock performance evaluated against a historical biomass level ($SB_0$) that is based on a different value for $M$ will also be highly uncertain.

Modelling results reflect only the structural assumptions specified in the model and weights assigned to the various data components, representing a minimum estimate of uncertainty. While uncertainty in the estimated parameters and derived quantities is explicitly addressed using a Bayesian approach, alternative model and stock structure assumptions - including alternative forecasting methods - would illustrate greater levels of uncertainty. Moreover, small sample sizes of age-composition samples are a concern in recent years.

## Ecosystem Considerations

Pacific Herring play a key role in marine ecosystems and are a food source for a variety of piscivorous species including Pacific Salmon (Coho – *Oncorhynchus kisutch*, and Chinook, *O. tshawytscha*), Pacific Hake (*Merluccius productus*), Halibut (*Hippoglossus stenolepis*), Arrowtooth Flounder (*Atheresthes stomias*), and Dogfish Shark (*Squalus acanthias*) (Schweigert et al. 2010). Herring are also believed to be important in the diet of marine mammal predators such as Steller (*Eumetopias jubatus*) and California (*Zalophus californianus*) Sealions, Harbour Seals (*Phoca vitulina*), Northern Fur Seals (*Callorhinus ursinus*), Harbour Porpoises (*Phocoena phocoena*), Pacific White-sided Dolphins (*Lagenorhynchus obliquidens*), Humpback Whales (*Megaptera novaeangliae*), and Grey Whales (*Eschrichtius robustus*). During the time period captured in the Pacific Herring assessment (1951-2014), population sizes of seals, sea lions and baleen whales, which forage on herring, have increased (DFO 2003; DFO 2010; Carretta et al. 2011; Crawford and Irvine 2011). Because of their important role in the food web, herring biomass is affected by the density of predators that consume them. Herring biomass may also affect predator biomass.

Researchers continue to develop a greater understanding of ecosystem processes and the role that herring play in the ecosystem. Little information is available to develop ecosystem-based conservation limits for herring at present but DFO has begun to compile data for evolving ecosystem modeling projects.

# CONCLUSIONS AND ADVICE

The Pacific Herring stock assessment depicts five major and two minor stocks with varying levels of productivity that have experienced heavy commercial fishing in the past (pre-1972). In the 2013/14 fishing season, commercial roe fishery opportunities were provided and pursued in the Prince Rupert District, Central Coast, and Strait of Georgia, and commercial spawn-on-kelp opportunities were provided and pursued in Area 2W, Area 27, PRD, and CC.

Advice for each Pacific Herring stock is presented in probabilistic decision tables showing predicted status in 2015 given a range of constant catches relative to harvest and spawning biomass metrics relating directly to the existing herring HCR. The assessment results and advice are summarized by management area.

Recommendations for future work follow:

- Develop survey and sampling protocols to meet current assessment objectives given future potential budgetary constraints.
- Characterize the uncertainty associated with the spawn index data.
- Evaluate the legitimacy of pre-processing surface spawn survey data and having two q's for two separate spawn index time series.
- Identify the cause of the apparent pattern in M during the post reduction fishery period (pre-1972 in Haida Gwaii and in other areas).
- Model the fishing year sequentially from food fishery to the spawning fisheries rather than assume that all fishing and natural mortality occurs simultaneously throughout the year.
- Incorporate sources of fishing mortality currently not accounted for in the assessment model.
- Investigate alternative formulations for reference points that are independent of the biological variations that appear to have occurred in this species so that management strategies can be more easily evaluated.
- Develop closed loop models for feedback simulations and sensitivity cases to test the effectiveness of existing and alternative management strategies.

## SOURCES OF INFORMATION

This Science Advisory Report is from the September 3-4, 2014 Stock Assessment and Management Advice for BC Pacific Herring: 2014 Status and 2015 Forecast. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada Science Advisory Schedule as they become available.

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