Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

Canadian Science Advisory Secretariat (CSAS)

Research Document 2014/113

Pacific Region

Review of harvest control rules for the Pacific Sardine *(Sardinops sagax)* population, and harvest advice for 2013 and 2014

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January 2015

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Florstrand, L., Schweigert, J., Boldt, J.L., McFarlane, S., and Mah, J. 2015. Review of harvest control rules for the Pacific Sardine (*Sardinops sagax*) population, and harvest advice for 2013 and 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/113. x + 63 p.

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ABSTRACT

Prior to and during summer months, large aggregations of the California Current sardine population migrate from key spawning habitat off California to more northern waters, but migratory patterns can be affected by population size and oceanographic conditions. DFO has been applying a Fishery Management Framework using a harvest control rule (HCR) that calculates annual total allowable catch (TAC) options of sardine in British Columbia (BC) waters as the product of three parameters:

1) An annually updated biomass estimate of age 1 and older (1+) fish in the population,
2) An estimated average seasonal migration rate of sardine into BC waters, and
3) A regional harvest rate of 15%.

Migration rate values have been based on estimates associated with an annual summer trawl survey off the west coast of Vancouver Island, BC. There are several concerns associated with annually updating the estimate of migration rate, one of which is that the trawl survey may not occur during a time representative of when sardine migration into BC waters has occurred. A second concern is the operational cost of annually conducting a survey and reporting on results.

This report presents results on the trends and status of sardine biomass and exploitation in the California Current population and in BC waters, including various determinations of migration rates, and describes three alternative types of HCRs that do not explicitly include a migration rate and which do not rely on information from an annual summer trawl survey. Collectively, regional and population biomass estimates indicate that the California Current sardine population biomass and migration to BC have decreased relative to 2011 and earlier years, whereas exploitation rates have increased, especially from 2011 to 2012 and in the Pacific Northwest. Of the three types of alternative HCRs that do not rely on annual observations from a summer trawl survey, two apply harvest rates on a population scale (rather than a regional scale), one of which includes an escapement buffer (cutoff) of 150,000t. The other type is one with a constant annual TAC, which is not sensitive to variations in population biomass and is believed to be the least precautionary and is therefore not supported. None of the four HCRs described in this report are fully compliant with DFO's Fishery Decision-making Framework but the one including the cutoff adheres to some principles of that policy. This report does not advise on actual harvest rates or harvest options because no objective and quantitative evaluations could be conducted and related to conservation measures, since conservation measures have not been defined. However, it does discuss uncertainty associated with scientific observations, HCR parameters and harvest options. One important conclusion is that at the higher harvest rates, not only will TACs and realized exploitation rates increase and be more variable, but uncertainty and possible risks to stock productivity and ecosystem dynamics will also increase. In the future, it would be valuable to thoroughly evaluate HCRs and related parameters, with the inclusion of defined uncertainty, conservation and fishery performance measures.

Examen des règles de contrôle des prises s'appliquant à la population de la sardine du Pacifique *(Sardinops sagax)* en Colombie-Britannique et avis sur les prélèvements de 2013 et 2014

RÉSUMÉ

Avant et pendant l'été, de grands rassemblements de la population de sardines du courant de Californie quittent les principales frayères se trouvant au large de la Californie pour migrer vers des eaux plus au nord. Toutefois, les habitudes migratoires peuvent varier en fonction de la taille de la population et des conditions océanographiques. Le MPO utilise un cadre de gestion des pêches qui fait appel à une règle de contrôle des prises (RCP), laquelle permet de calculer les options relatives au total autorisé des captures (TAC) annuel en ce qui concerne la sardine vivant dans les eaux de la Colombie-Britannique (C.-B.), à partir des trois paramètres suivants :

1) estimations annuelles à jour de la biomasse des sardines d'âges 1 et plus (1+) au sein de la population;
2) estimation du taux moyen de migration des sardines dans les eaux de la C.-B. et
3) taux de récolte régional de 15 %.

Les taux de migration sont basés sur les estimations liées à un relevé au chalut annuel effectué au large de la côte ouest de l'île de Vancouver, en C.-B. La mise à jour annuelle de l'estimation du taux de migration suscite plusieurs préoccupations. On craint, entre autres, que le relevé au chalut ne soit pas effectué à une période représentative du moment où la sardine migre vers les eaux de la C.-B. On s'inquiète aussi en ce qui a trait au coût opérationnel de la réalisation du relevé annuel et de la communication des résultats.

Ce rapport présente les résultats sur les tendances et la situation en ce qui concerne la biomasse de la sardine et l'exploitation de l'espèce dans le courant de Californie et les eaux de la C.-B. Il comprend diverses analyses des taux de migration et décrit trois autres types de RCP qui n'incluent pas explicitement un taux de migration et qui ne sont pas basés sur les données d'un relevé au chalut annuel effectué pendant l'été. Dans l'ensemble, les estimations régionales de la biomasse indiquent que la biomasse de la population de sardines du courant de Californie et la migration de l'espèce vers les eaux de la C.-B. sont en déclin par rapport à 2011 et aux années antérieures. En revanche, les taux d'exploitation ont augmenté, surtout de 2011 à 2012 et dans le nord-ouest du Pacifique. Parmi les trois autres types de RCP non basés sur les observations d'un relevé au chalut annuel effectué l'été, deux utilisent des taux de récolte à l'échelle de la population (plutôt qu'un taux à l'échelle régionale), dont l'un comporte une valeur tampon (valeur seuil) de 150 000 tonnes. L'autre type de RCP utilise un TAC annuel constant qui n'est pas sensible aux variations de la biomasse de la population. Étant considéré comme le type de RCP le moins prudent, son utilisation n'est pas encouragée. Des quatre RCP décrites dans ce rapport, aucune n'est parfaitement conforme au cadre décisionnel du MPO utilisé pour les pêches. Toutefois, celle comportant une valeur seuil répond à certains principes de cette politique. Ce rapport ne donne aucun renseignement sur les taux de récolte réels et les options de prélèvement, étant donné qu'aucune évaluation quantitative objective n'a pu être menée et que les mesures de conservation n'ont pas été définies. Il informe néanmoins sur l'incertitude entourant les observations scientifiques, les paramètres des RCP et les options de prélèvement. Une conclusion importante qu'on peut tirer est que, lorsque les taux de récolte sont élevés, il n'y a pas que les TAC et les taux d'exploitation qui augmentent. L'incertitude et les risques potentiels pour la productivité des stocks et les dynamiques de l'écosystème augmentent eux aussi. Il serait utile d'évaluer en profondeur les RCP et leurs paramètres, à partir d'un degré d'incertitude et de mesures de conservation et de rendement de la pêche définis.

1. INTRODUCTION

1.1. CONTEXT

Since 2002, Fisheries & Oceans Canada (DFO) has been applying a Fishery Management Framework using a harvest control rule (HCR) that calculates annual total allowable catch (TAC) options of Pacific Sardine (*Sardinops sagax*) in British Columbia (BC) waters as the product of three parameters, 1) an annually updated biomass estimate of age 1 and older (1+) fish in the population from the previous year, 2) an estimated average seasonal migration rate of sardine into BC waters, and 3) a regional harvest rate. Average migration rate estimates applied to this harvest control rule have ranged from 10-27% in conjunction with a regional harvest rate of 15%, (Schweigert and McFarlane 2001, Schweigert et al. 2010, DFO 2012a).

Since 1997, an index of the biomass of the migratory component of the sardine population occurring in BC waters has been determined from an annual summer surface trawl survey off the west coast of Vancouver Island (WCVI, Schweigert and McFarlane 2001, DFO 2012a). The index is based on average sardine trawl densities observed for the region and season. Prior to 2006, surveys were conducted primarily during the day but in order to try to reduce trawl density variability, starting in 2006, surveys have been conducted at night. In addition to survey observations, sardine fishery catch locations have been considered to represent potential sardine habitat in unsurveyed areas. Biomass estimates for unsurveyed areas have been estimated by extrapolating annual trawl survey densities from night surveys to areas with recent commercial purse seine fishing (Flostrand et al. 2011, DFO 2012a).

In anticipation of reductions in funding and to permit exploration of other aspects of sardine ecology, both DFO and the sardine fishing industry wanted to consider alternative approaches to the provision of harvest advice that do not rely on an annual trawl survey. In addition, the fishing industry has expressed interest in having stability in the TAC. Moving towards multi-year science advice is consistent with goals of DFO Fisheries Renewal and is one of the key objectives of Fisheries Management. To address these multiple interests, a request from DFO Fishery Management included several objectives associated with the provision of advice for the 2013 sardine fishing season that were incorporated into the terms of reference for a Canadian Science Advisory Secretariat (CSAS) review. Those objectives are listed below and were used as a guide to develop this report. Due to time and information constraints, some of the objectives (2 and 3) could not be addressed because there was not sufficient time or resources to complete simulation modeling necessary to address these objectives. Also, conservation and fisheries management performance measures have not been defined.

1. Provide estimates of the 2012 mid-summer BC Pacific Sardine seasonal biomass and migration rate.
2. Evaluate approaches for characterizing the migratory component of Pacific Sardine biomass in BC waters that are not reliant on annual surveys.
3. Evaluate potential harvest rates appropriate for the sardine population biomass estimates in BC waters.
4. Consider the inclusion of a population biomass cutoff into a harvest control rule applicable to setting TACs in BC waters.
5. Identify any specific concerns, uncertainties or information gaps that should be considered when setting the TAC for the 2013 fishing season and when evaluating competing harvest control rules.

Ongoing communication with Fisheries Management occurred during the development of this report to ensure the report sufficiently addressed key questions for the provision of advice applicable to the 2013 fishing season. This report presents the trends and status of sardine biomass and exploitation in the California Current population and in BC waters, including various determinations of migration rates, and describes three alternative types of HCRs that do not explicitly include a migration rate or rely on information from an annual WCVI trawl survey.

1.2. ABUNDANCE AND DISTRIBUTION

The California Current Pacific Sardine population is a pelagic schooling fish that, when abundant, occupies coastal waters from Baja California to southeast Alaska (Schweigert 1998). In winter and spring months, most of the sardine population resides in waters off the California coast. Prior to and during summer months, large aggregations of sardine migrate from key spawning habitat to more northern waters, but migratory patterns can be affected by population size and oceanographic conditions.

The Pacific Sardine is an opportunistic life history strategist, which occupies pelagic habitat with a high degree of spatial and temporal variability (King and McFarlane 2003). Opportunistic strategists have a short generation time which maximizes their intrinsic rate of population growth despite having relatively low individual fecundity and their population responses tend to be large in amplitude. Abundance and distribution of these opportunistic strategists are known to fluctuate concurrently with climate-ocean regimes (Beamish et al. 2000, Hare and Mantua 2000). Within a regime period, their abundance and distribution is dynamic, and across regime periods the populations experience high amplitude of variability.

The California Current Pacific Sardine population has undergone long term cycles in abundance (Baumgartner et al. 1992, Chavez et al. 2003). In the last century, large abundances occurred along the entire west coast of North America from the early 1900s to the late 1940s when their abundance declined and their distribution contracted to small areas off southern California. The population did not rebuild until the 1980s when abundance began to increase, reaching high levels by the mid-1990s (McFarlane et al. 2002, Hill et al. 2012). Baumgartner et al. (1992) showed that large scale abundance fluctuations, with a period between 30 and 60 years, were characteristic of the dynamics of the Pacific Sardine population for the past 1600 years. As the population showed signs of recovery in the Northeast Pacific during the most recent cycle, the distribution expanded and sardines resumed annual northward migrations to waters off Oregon, Washington and BC (Hargreaves et al. 1994, McFarlane and Beamish 2001)..

Population size and age composition coupled with coastwide fluctuations in climate/ocean conditions contribute to the variability in timing and extent of seasonal BC sardine migration (Emmett et al. 2005, Lo et al. 2010). In recent years of high sardine biomass (e.g. 2006), BC biomass and migration rate were also high, which was attributed to strong cohorts in the population and favourable ocean conditions (Flostrand et al. 2011, DFO 2012a). Typically, larger and older components of the California Current sardine population migrate to BC, Washington, and Oregon waters (Lo et al. 2010, Flostrand et al. 2011, Hill et al. 2012). Past observations have shown that most of the sardine biomass in BC waters has been comprised of fish that are 20 cm or longer in fork length (20+ cm FL) and age 3 and older (3+); however, up to 30% of the number of fish observed in catch samples has been comprised of younger fish (McFarlane et al. 2005, Flostrand et al. 2011, DFO 2012a).

1.3. POPULATION ASSESSMENT & U.S. HARVEST CONTROL RULE

The United States of America (U.S.) federal fisheries agency has annually assessed the trends and status of the California Current sardine population by estimating abundance, recruitment, age and length compositions using a Stock Synthesis (SS) assessment model that integrates data from research surveys and commercial catches (Hill et al. 2012). The assessment has been conducted in the fall and has annually determined a pre-season age 1+ biomass estimate which represents available biomass as of the preceding July. In the U.S., the annual total allowable catch ($TAC_{US,y}$) in recent years has been based on a HCR that consists of the product of three terms: 1) a July pre-season SS estimate of the sardine biomass of age 1 and older ($B_{1+,y-1}$) minus a fixed escapement buffer of 150,000 t (referred to as the “cutoff”), 2) a “distribution factor” (d_{US}) of 0.87, which was intended to represent the proportion of the sardine population that occurs on average in U.S. waters and is based on historical observations from Mexico and the U.S., and 3) a harvest rate “fraction” (h_{US}), representing a proportion of age 1+ biomass above the cutoff. The U.S. fraction has been 0.15 in recent years but was intended to vary with measurements of sea surface temperatures at Scripps Pier (La Jolla, California). In the U.S., the potential annual total allowable catch ($TAC'_{US,y}$, in metric tonnes) for a given year (subscript y) has been calculated as:

$$TAC'_{US,y} = (B_{1+,\,y-1} - 150{,}000) \times d_{US} \times h_{US} \tag{1}$$

The U.S. HCR inclusion of a 150,000 t cutoff and the distribution factor reduces the effective harvest rate to less than h_{US} (e.g. <0.15), and the degree of this reduction varies inversely with the magnitude of age 1+ biomass estimates ($B_{1+,\,y-1}$). Due to the cutoff, the reduction will be greater at low population biomass estimates than at higher estimates.

The U.S. Pacific Fishery Management Council considers resulting $TAC'_{US,y}$ amounts to determine actual TACs for the U.S. fishery ($TAC_{US,y}$). A $TAC_{US,y}$ is applicable to a fishery year that matches the calendar year and the $TAC_{US,y}$ can be taken from any or all of the three west coast states (California, Oregon, and Washington), although seasonal allocations apply.

The U.S. sardine HCR originated from a 1998 Coastal Pelagic Species Management Plan (Pacific Fishery Management Council 1998) and was one of thirteen candidate HCRs investigated with the objective of maintaining the sardine population at levels well above that which would occur with a single-species maximum sustainable yield (MSY). This HCR was selected because simulations indicated that it should maintain a relatively productive population, while providing forage for sardine predators. Also, the HCR was adopted based on its ability to meet a number of performance measures: high average biomass, high median biomass, high standard deviation of biomass, low percentage of years with biomass less than 400,000 t (a level at which, historically, the population appeared to be restricted to the area south of Point Conception), average catch near 147,000 t, high median catch, low standard deviation of catch, and a low percentage of years with no fishery.

1.4. BC SARDINE FISHERY

The recent commercial BC sardine fishery reinitiated in 2002 and uses purse seines. The fishery has mainly been conducted in inshore waters within the inlets of the west coast of Vancouver Island, and in some oceanographically favourable years, has extended northward to inlets of the south Central Coast and eastward into northern Queen Charlotte Sound. To date, the BC fishery has been based on a June 1 to February 9 seasonal opening, and the majority of each season’s TAC has been taken in July to October (DFO 2012b). The BC sardine fishery targets the older and larger fish in the population that generally occur in BC waters.

1.4.1. DFO Management and BC harvest control rule

The objective of the current DFO fishery management framework is to ensure sustainable resource utilization and generate economic prosperity, accomplished through close collaboration with resource users and stakeholders based on shared stewardship consistent with treaty and Aboriginal rights (DFO 2012b). No formal agreement exists between Canadian, U.S. and Mexican governing agencies on coordinated approaches to sardine assessment or management frameworks. However, in parallel with the U.S. sardine management objectives, DFO has developed management objectives that broadly encompass the issues of sustainability, certainty and stability of the fishery (DFO 2012b).

Development of the BC sardine fishery HCR occurred prior to the introduction of the Sustainable Fisheries Framework in 2009. The Precautionary Approach currently requires the three components listed below (DFO 2009a). Additionally, there is a requirement for regular evaluation of the performance of the management system to assess the ability of the system to avoid lower limits and achieve targets.

1. Reference points and stock status zones labeled Healthy, Cautious and Critical.
2. Harvest strategy and harvest decision rules.
3. The need to take into account uncertainty and risk when developing reference points and developing and implementing decision rules.

Since the 2002 initiation of the recent commercial BC sardine fishery period, DFO has applied a Fishery Management Framework using a HCR with annual TAC options ($TAC'_{BC,y}$, in metric tonnes) for a fishing season beginning in year y, as the product of three values: 1) a previous season's July SS age 1+ population biomass estimate ($B_{1+,\,y-1}$); 2) a multi season average BC sardine migration rate ($\bar{m}_{1+}$) designed to characterize an average proportion of the age 1+ population biomass that enters BC waters, and 3) a BC regional harvest rate (h_{BC}), which was 0.15 during 2002-2012:

$$TAC'_{BC,y} = B_{1+,\,y-1} \; x \;\; \bar{m}_{1+} \; x \;\; h_{BC} \qquad (2)$$

Ware (1999) initially recommended a BC fishery HCR that included a July age 1+ SS model population estimate and a BC migration rate. Ware (1999) also recommended a conservative harvest rate fraction and, in following with the U.S. HCR, the inclusion of a 150,000t cutoff and the 0.87 U.S. distribution factor. These recommendations were made at a time when Pacific Sardine was still listed as "Special Concern" under COSEWIC (*Committee on the Status of Endangered Wildlife in Canada*) and when only experimental fishing was allowed in BC waters. Subsequent to recommendations made by Schweigert and McFarlane (2002), the BC harvest rate fraction was set to match the value of the U.S. fraction parameter (h_{US}) but the cutoff and distribution parameters were omitted from a BC fishery HCR equation.

Migration rates applied to the BC fishery HCR have varied from 0.10 to 0.27 based on averages of seasonal estimates (Schweigert and McFarlane 2001, Schweigert et al. 2010, DFO 2012a). From 2002 to 2008, the migration rate was kept constant at 0.10 based on interpretation of average ratios from two methods. One method used ratios of historical BC fishery catch landings to BC plus U.S. fishery catch landings (Ware 1999) and the other method used ratios of BC regional biomass estimates from summer WCVI trawl survey sardine catch density estimates to age 1+ SS model population biomass estimates applied by Schweigert and McFarlane (2001). Following recommendations associated with the review of Schweigert et al. (2010), HCR equations used for determining TAC options for the 2009 to 2012 fishing seasons included annually varying migration rates (e.g. from 0.18 to 0.27). The migration rates were based on annually updated average ratios of BC seasonal biomass estimates (derived from WCVI trawl survey sardine catch density observations) to July age 1+ SS model biomass estimates for a series of years ending in the previous survey year (e.g. $\bar{m}_{1+,y-1}$).

There are concerns with annually varying migration rates in the BC fishery HCR. From an industry and management perspective, applying a rolling average of past migration rate estimates introduces additional variability between years to the resulting TAC amounts, which may reduce the stability of the fishery. From a science perspective and in the context of forecasting regional biomass for a coming fishing season, applying a rolling average estimate may have poor forecasting power because sardine migration into BC waters is influenced by biological and environmental processes that can change considerably among years and within seasons. There are also potential discrepancies between survey timing and the occurrence of favourable environmental conditions for sardine movement into BC waters and there have been discrepancies between the spatial and temporal coverage of the survey relative to the commercial fishery.

In anticipation of reductions in assessment funding, and to permit exploration of other aspects of sardine ecology, both DFO and the sardine fishing industry were interested in considering alternative approaches to the provision of harvest advice that do not rely on an annual trawl survey. In light of this, Fisheries Management put forward the following management objectives when considering the development of new harvest control rules:

1. Minimize risk to the status of the stock, to habitat and other ecosystem components (DFO's Fishery Decision-making Framework incorporating the Precautionary Approach);
2. Implement multi-year science advice (e.g. multi-year management plans, harvest levels etc);
3. Enable annual harvest levels that are opportunistic given the variable nature of sardine abundance in BC waters; and,
4. Move towards a more stable estimate of migration or a more stable combined migration and harvest rate parameter in harvest control rules since the fishing industry has expressed interest in having stability in the TAC.

1.5. SCOPE OF THE REPORT

This paper describes sardine biomass trends for the California Current population and in BC waters, as well as describes different estimates of migration and exploitation rates associated with those biomass estimates. The paper also describes three alternative HCRs for consideration for the BC fishery that do not rely on BC observations from an annual trawl survey.

For reference purposes and to facilitate future considerations , alternative estimates of population biomass were included and used to estimate sardine migration and exploitation, based on concerns voiced at a 2012 CSAS review (DFO 2012c), pertaining to:

1. The population's biomass, age and size composition can change considerably during a year; therefore there is a perceived high level of uncertainty and risk associated with using a SS model age 1+ population biomass estimate from a previous season that lags the BC fishing season applicable to a TAC option by 1 year.
2. Since age 1 and 2 fish typically comprise relatively low proportions of the biomass observed in BC waters, methods that use SS model age 1+ population biomass estimates for annual updates of biomass and migration rates may not be the most appropriate. Alternative methods could include the use of biomass estimates for older (and larger) cohort groups.
3. Since biomass estimates determined from the SS assessment model and WCVI trawl survey have different error structures and assumptions, other population biomass estimates could be applied to estimate seasonal migration. For example, it was

suggested that acoustic-trawl (AT) survey population biomass estimates could be applied as denominators in the calculation of BC migration rates since AT surveys are fishery independent and are based on empirical observations, as is the WCVI trawl survey.

This report describes and compares four types of HCRs. Type 1 HCR is based on the recent BC fishery HCR but includes alternative methods to set migration rates, all using information collected from WCVI trawl surveys. Three other types of HCRs are provided as examples that do not rely on observations from a WCVI trawl survey, or that do not rely on any new data collection from BC waters. Type 2 HCR uses a harvest rate fraction at a population scale (rather than a BC regional scale) and Type 3 HCR is similar to Type 2 but includes an escapement buffer (cutoff) of 150,000t. Type 4 HCR is simply a constant annual TAC. Types 2 and 3 are linked to U.S. SS assessment model results and Type 4 is similar to a HCR that is used for the South Australia sardine fishery (Ward et al 2008). Values used in the four HCRs were chosen and evaluated based on retrospective migration and exploitation rate estimates. In the future, competing HCRs should be evaluated in a more analytical framework with simulation, consultation, and explicit conservation and management performance measures. Summary statistics (mean, median, ranges and variance etc.) for observed, estimated and hypothetical TACs, TAC ratios and exploitation rates presented herein may provide insights into future science investigation or fishery management.

2. ASSESSMENT METHODOLOGY AND SOURCES OF INFORMATION

2.1. STOCK STATUS AND TRENDS

2.1.1. Population observations

Annually, scientists in the U.S. assess the California Current sardine population distributed from northern Baja Mexico (e.g. off Ensenada) to BC, using an age structured Stock-Synthesis (SS) assessment model (Hill et al. 2012). The 2012 version of the SS model incorporated fishery data (landings and biological data) and research survey data (both biomass and biological data) from acoustic-trawl, aerial and ichthyoplankton surveys from 1993 to 2012 (Hill et al. 2012). Conditional age-at-length relationships were updated and biomass estimates representing different age and size components of the population were generated by the 2012 SS assessment, denoted as version X6e. Reported SS model time series of population biomass estimates represent the start of July (Semester 1) of a given model year (which extends from July to June). This report includes SS model (version X6e) 1993 -2012 time series biomass estimates for fish age 1 year and older (age 1+), 2 years and older (2+), 3 years and older (3+) and 20 cm fork length and longer (20+cm FL) as well as recruitment year class estimates (number of fish) reported in Hill et al. (2012).

Also included in this report are sardine population biomass estimates from two sets of acoustic-trawl (AT) surveys (Zwolinski et al. 2011, Demer et al. 2012, Zwolinski et al. 2012 *in Hill et al. 2012*). Estimates resulting from the AT surveys are based on fishery-independent information, therefore providing an alternative view of trends in population biomass and size composition. Spring AT surveys were conducted in 2006, 2008, 2010-2012 off the coast of California with the goal of sampling the spawning population while it was spatially concentrated in key spawning habitat. Summer AT surveys were conducted in 2008 and 2012 from marine waters off the U.S.-Mexico border to the northwest coast of Vancouver Island. The goal of the summer AT surveys was to sample sardine in their foraging habitat. Sardine standard length distributions for each AT survey are included in an appendix.

Sardine length measurements represented by the SS model are in standard length (SL) whereas sardine length measurements recorded from BC samples are in fork length (FL). Length classes associated with SS model biomass estimates were converted from SL (cm) to FL (cm) using:

$$FL = 1.04 \times SL + 0.412 \tag{3}$$

SL refers to the distance between the most anterior part of a fish and the posterior end of the hypural plate. FL refers to the distance between the most anterior part of a fish and the end of the middle caudal fin rays. Typically for fish measuring 15-25 cm SL, FL measurements are approximately 1 cm longer than SL; therefore sardines recorded as being 19cm SL convert to being 20cm FL (Appendix C).

2.1.2. BC biomass

Starting in 1997, summer research surveys using surface trawl nets were designed to examine trends in sardine regional distribution, relative abundance and size and age compositions in BC waters during peak periods of migration (McFarlane et al 2005; McFarlane pers. comm). Research surveys have occurred almost annually from 1997 to 2012, but there has been variation in the scheduling, regional coverage and sample design of the summer surveys. Observed sardine trawl catch densities are assumed to be indicative of the relative biomass of sardine in the survey region at the time each survey is conducted. The WCVI trawl survey has been conducted at night since 2006, mostly in a defined core survey region (CSR) as described in Flostrand et al. (2011). Inlets are not included within the CSR due to survey design and resource constraints. The 2012 survey was conducted from July 18 to August 2. For each trawl tow, a sardine catch density estimate was derived as the total weight of sardine (tonnes per tow) divided by an estimate of the volume of water swept while fishing (km^3). The volume of water was determined by multiplying the length and width dimensions of the trawl net mouth by the effective fishing distance covered during the tow (distance over ground between end of net deployment and beginning of net retrieval). For each survey year, the geometric mean of the CSR sardine trawl densities was calculated ($\overline{D}_{CSR,y,}$ in units tonnes/ km^3) and 90% confidence limits ($\overline{D}_{LL,y}$= lower limit, $\overline{D}_{UL,y}$= upper limit) were estimated from bootstrap sampling across all tows (Efron, 1981).

Catch densities were assumed to represent sardine distributions in the top 30 m of the water column. The CSR area is approximately 16,740 km^2 and therefore the surface volume of the CSR (V_{CSR}) was estimated as 502.2 km^3 (Flostrand et al. 2011). For each year of the night survey period (2006, 2008-2012), estimates of sardine biomass in the CSR ($I_{CSR,y}$) and corresponding 90% lower ($I_{LL,y}$) and upper ($I_{UL,y}$) confidence limits were calculated by multiplying density estimates ($\overline{D}_{CSR,y}$, $\overline{D}_{LL,y}$, and $\overline{D}_{UL,y}$) by the volumetric estimate representing surface habitat in the CSR, as follows:

$$I_{CSR,y} = \overline{D}_{CSR,y} \times V_{CSR} \tag{4a}$$

$$I_{LL,y} = \overline{D}_{LL,y} \times V_{CSR} \tag{4b}$$

$$I_{UL,y} = \overline{D}_{UL,y} \times V_{CSR} \tag{4c}$$

where $V_{CSR} = 502.2\ km^3$

where index y indicates the year associated with a survey or biomass estimate

For each year of the night survey period, additional sardine biomass potentially occurring in unsurveyed regions of the BC coast was estimated by extrapolating mean CSR densities over surface volume estimates of inlets that were fished for sardine at least once during the 2006 to 2010 seasons. This is referred to as inlet extrapolation (IE). The unsurveyed areas represent some mainland inlets (area = 2,418 km^2) and WCVI inlets (area = 1,047 km^2). The sum of the unsurveyed areas was estimated as 3,465 km^2. By assuming sardine habitat and distribution in the top 30m of the water column in these areas, a volumetric estimate of 103.9 km^3 (V_{IE}) was calculated to represent additional potential sardine habitat in inlets (Flostrand et al. 2011). For each year, summer estimates of sardine biomass in the unsurveyed inlets were calculated as follows:

$$I_{IE,y} = \overline{D}_{CSR,y} \times V_{IE} \tag{5}$$

where $V_{IE} = 103.9\ km^3$

The sum of the CSR +IE volumetric estimates is 609.1 km^3. Estimates of sardine biomass in BC waters representing both the CSR and region of IE were calculated by summing the CSR and IE biomass estimates by year:

$$I_{CSR+IE,y} = I_{CSR,y} + I_{IE,y} \tag{6}$$

2.1.3. BC migration rates

Estimates of migration represent the proportion of the adult sardine population biomass occurring mid-summer in BC waters. This report estimates several types of annual migration rates ($m_{i,b,y}$) as the ratio of BC biomass estimates ($I_{i,y}$) to population biomass estimates ($B_{b,y}$) for the years 2006, 2008-2012:

$$m_{i,b,y} = I_{i,y} / B_{b,y} \tag{7}$$

where index *i* indicates regional depiction of British Columbia waters, representing either:

- CSR: core survey region alone
- CSR+IE: core survey region plus inlet extrapolation

where index *b* indicates population biomass estimate, representing one of:

- 1+: Stock Synthesis age 1 and older (July status)
- 2+: Stock Synthesis age 2 and older (July status)
- 3+: Stock Synthesis age 3 and older (July status)
- 20+ cm FL: Stock Synthesis 20 cm fork length and longer (July status)
- ATsp: spring acoustic-trawl survey
- ATsu: summer acoustic-trawl survey

Multi-season average migration rate estimates, based on either two or three-year averages, were calculated as the ratio of summer BC biomass estimates for region *i* to population biomass estimates of type *b* for a series of years ending in *y*:

Three-year average:

$$\bar{m}_{i,b,y} = (I_{i,y} + I_{i,y-1} + I_{i,y-2}) / (B_{b,y} + B_{b,y-1} + B_{b,y-2}) \quad (8a)$$

Two-year average:

$$\bar{m}_{i,b,y} = (I_{i,y} + I_{i,y-1}) / (B_{b,y} + B_{b,y-1}) \quad (8b)$$

Longer term multi-season average migration rate estimates were also calculated for all the night survey years (2006, 2008-2012, denoted by $\hat{m}_{i,b,2006\text{-}2012}$) or for all night survey years but 2012 (denoted by $\hat{m}_{i,b,2006\text{-}2011}$). This was done in part to show the effect of including or excluding results related to the 2012 WCVI trawl survey.

$$\hat{m}_{i,b,2006-2012} = \sum_{y=2006}^{2012} \left(I_{i,y}/B_{b,y}\right) \quad (9a)$$

$$\hat{m}_{i,b,2006-2011} = \sum_{y=2006}^{2011} \left(I_{i,y}/B_{b,y}\right) \quad (9b)$$

2.1.4. BC length and age data

Sardine fork length (FL) measurements from fresh samples (75-200 fish per tow) were collected from research trawl surveys off the west coast of BC during years 2000-2006 and 2008-2012 and were statistically weighted by sardine catch density of each trawl tow. Information on trawl surveys and sample collection prior to 2006 is described in McFarlane et al. (2005).

Sardine fork length measurements were also obtained from fresh and frozen samples (75-100 fish per seine set or offload) collected from experimental seine fishing (2000 and 2001) and from commercial seine fishing (2002-2012), and pooled by year. Fresh samples were generally collected from individual seine sets and frozen samples were generally collected during offloading and may represent multiple sets. For each year, sample collection occurred across fishery management area and week combinations applicable to fishing.

Age and fork length data were also obtained from frozen samples (30-75 fish per set) collected from trawl surveys and commercial seine catches and pooled by year (1999-2012). Age data were obtained from otoliths which were aged predominantly from surface reading methodology, although some samples were also polished prior to reading (McFarlane et al. 2010). Ideally, frozen age and length sample data would have been statistically weighted by catch per unit effort but sample allocation within and between research and commercial sources confounded that approach.

2.1.5. Fishery exploitation

This report includes annual TAC and reported catch amounts (landings) for BC and U.S. sardine fisheries during the recent commercial BC sardine fishery period (2002-2012). The ratios of either annual TAC or catch amounts to biomass estimates were included to track and compare trends in fishing allowances and exploitation. The use of the term “exploitation rate” (denoted by a u) is defined herein as a ratio of a reported annual catch amount (C_y) to an annual estimate of sardine biomass ($I_{i,y}$ or $B_{b,y}$), whereas the terms “harvest rate”, or “harvest rate fraction” (denoted by an h), refer to a fraction used in a HCR.

To estimate annual population TAC ratios ($p_{c,b,y}$), the ratio of a country’s TACs (or sums of TACs for combined countries) to type b population biomass estimates was calculated:

$$p_{c,b,y} = TAC_{c,y} / B_{b,y} \quad (10)$$

where index c indicates the country or combined countries of the total allowable catch, representing one of:

- BC: Canada (British Columbia)
- US: United States
- BC+US: British Columbia and the United States combined

To estimate annual population exploitation rates ($u_{c,b,y}$), the ratio of catch amounts (by country, or countries or regions combined) to type b population biomass estimates was calculated:

$$u_{c,b,y} = C_{c,y} / B_{b,y} \quad (11)$$

where index c indicates country or regional grouping of landed catch, representing one of:

- BC: Canada (British Columbia)
- US: United States
- BC+US: British Columbia and the United States combined
- PNW: Pacific Northwest (British Columbia, Washington and Oregon combined)

To estimate annual BC regional TAC ratios ($p_{i,y}$) for years corresponding to the WCVI night trawl surveys (2006, 2008-2012), the ratio of BC fishery TAC amounts to type i BC biomass estimates was calculated:

$$p_{i,y} = TAC_{BC,y} / I_{i,y} \quad (12)$$

To estimate annual BC regional exploitation rates ($u_{i,y}$) for years corresponding to the WCVI night trawl surveys (2006, 2008-2012), the ratio of BC fishery catch amounts to type i BC biomass estimates was calculated:

$$u_{i,y} = C_{BC,y} / I_{i,y} \quad (13)$$

2.2. HARVEST CONTROL RULE SCENARIOS

Four different types of HCRs are described in this report for possible consideration for future BC sardine fishery management. For each type, hypothetical scenarios represent annual BC sardine fishery TAC amounts (denoted as TAC'_y) and population TAC ratios (denoted as p'_y). No uncertainty or feedback steps were included in the HCR calculations to introduce variability, error or fishing effects on population biomass.

The calculations of hypothetical TACs are described below for each HCR. Hypothetical TAC ratios for all scenarios were calculated as the ratio of hypothetical TAC amounts to corresponding year SS model population biomass estimates across a time series ending in year 2012 (Hill et al 2012), as follows:

$$p'_{b,y} = TAC'_y / B_{b,y} \quad (14)$$

where index b indicates population biomass estimate, representing one of:

- 1+: Stock Synthesis age 1 and older (July status)
- 2+: Stock Synthesis age 2 and older (July status)
- 3+: Stock Synthesis age 3 and older (July status)
- 20+ cm FL: Stock Synthesis 20 cm fork length and longer (July status)

2.2.1. Type 1: $B_{1+,y-1}$ $m_{i,1+}$, $x\ 0.15$ (includes status quo)

The first type of HCR is based on three parameters: a previous season SS model age 1+ biomass estimate ($B_{1+, y-1}$), one of three types of age 1+ migration rates ($m_{i,1+}$) and a fixed regional harvest rate fraction of 0.15 (h_{BC}= 0.15). The three sets of age 1+ migration rates used in HCR calculations were actual estimates representing age 1+ migration rates for BC biomass in the CSR and with inlet extrapolation (CSR+IE) across years 2006, 2008-2012 (described in Section 3.1.3).

Type 1 hypothetical TACs were calculated for fishing seasons starting in year y (ranging from 2007 to 2012) as follows:

$$TAC'_y = B_{1+,\, y-1} \times m_{i,1+} \times h_{BC} \tag{15}$$

where $m_{i,1+}$ is one of the following estimates of an age 1+ migration rate:

- $m_{i,1+,y-1}$
- $\overline{m}_{i,1+,y-1}$
- $\widehat{m}_{i,1+,2006\text{-}2012}$

From 2009 to 2012, BC fishery TAC amounts ($TAC_{BC,y}$) were based on a HCR that used estimates of $\overline{m}_{i,1+,y-1}$;therefore the three-year rolling average of recent age 1+ migration rates can be considered the status quo. The other representations of age 1+ migration rates were included in reported scenarios for purposes of demonstration and comparison.

2.2.2. Type 2: $B_{1+,y-1}$ x h_{1+}

The second type of HCR is based on the product of a previous season SS model age 1+ biomass estimate ($B_{1+, y-1}$) and a fixed age 1+ population harvest rate fraction (h_{1+}). This HCR does not depend on BC biomass or migration rate estimates using data from the standardized WCVI trawl survey. A range in h_{1+} values from 0.02 to 0.05 was used to encompass: 1) realized estimates of 2009-2012 SS model age 1+ and 2+ population TAC ratios and exploitation rates, and 2) values resulting from the product of a BC fishery regional harvest rate (h_{BC}) of 0.15 and annual estimates of age 1+ and 2+ migration rates across years 2006, 2008-2012 (Section 3.1.3).

Type 2 hypothetical TACs were calculated for fishing seasons starting in year y (ranging from 1994 to 2012) as follows:

$$TAC'_{,y} = B_{1+,\, y-1} \times h_{1+} \tag{16}$$

where h_{1+} is a harvest rate fraction across the range of 0.02 - 0.05 (with 0.005 increments)

2.2.3. Type 3: $(B_{1+,y-1} – 150{,}000) \times h_{1+}$

The third type of HCR is based on the product of a previous season SS model age 1+ biomass estimate in excess of an escapement buffer (cutoff) of 150,000 t (e.g. $B_{1+,y-1}$ *-150,000*) and a fixed population harvest rate fraction (h_{1+}). The role of the cutoff is to reduce the effective harvest rate when population biomass decreases and to provide an escapement buffer, below which fishing ceases. This HCR does not depend on annual biomass or migration rate estimates from the standardized WCVI trawl survey.

Type 3 hypothetical TACs were calculated for fishing seasons starting in year y (ranging from 1994 to 2012) as follows:

$TAC'_y = (B_{1+,\,y-1} - 150{,}000) \times h_{1+}$ where h_{1+} is a harvest rate fraction across the range of 0.02 - 0.05 (with 0.005 increments) (17)

2.2.4. Type 4: constant annual TAC

The final type of HCR was a constant annual TAC demonstrated across a range from 15,000-45,000 tonnes with 5,000 tonne increments, requiring no updated estimates of BC or population biomass or migration rates. The lower value was chosen because it approximates observed median and mean values of 2002-2012 BC fishery TAC amounts, which are 15,200 and 16,417 t. The upper value was chosen because it approximates observed median and mean values of 2002-2012 landings from the Pacific Northwest (BC, Washington and Oregon combined), which were 44,941 and 49,638 t (Section 3.1.5).

3. RESULTS

3.1. STOCK STATUS AND TRENDS

3.1.1. Population observations

The 2012 sardine population SS assessment model indicated that age 1+ biomass increased after 1993 and peaked at approximately 1,300,000 t in 1999, 2006 and 2007 (Hill et al. 2012, Figure 1). The population declined during 2006-2012 with a 2012 age 1+ population biomass estimate (as of July) of 659,539 t (Table 1, Figure 1). Compared on average to age 1+ biomass estimates across the 1993-2012 time series, age 2+ biomass was 19% lower, age 3+ biomass was 41% lower and 20+ cm FL biomass was 44% lower (Table 2). Age 3+ and 20+cm FL biomass estimates were very similar for most years.

With the exception of 2006 and 2010 spring AT survey biomass estimates, AT survey biomass estimates were similar in magnitude to the SS model age 3+ and 20+ cm biomass estimates (Figure 1 and Table 1). The 2006 AT survey estimate was notably high and the 2010 AT survey estimate was notably low. Biomass estimates from the 2012 AT spring and summer surveys were 469,480 and 340,831 tonnes, respectively.

The SS model estimated strong recruitment of the 2003 year class, which is believed to have contributed large proportions of biomass to the population for several years and to the peak in biomass in 2006 and 2007 (Figure 2). The 2005 year class is also estimated to be strong, whereas recruitment of the 2006-2011 year classes was relatively low to moderate and corresponds to a declining trend in biomass estimates for 2006 to 2012 (Figures 1 and 2).

3.1.2. BC biomass

Annual sardine trawl survey mean catch densities and biomass estimates showed a declining trend from 2006 to 2010, an increase in 2011 and then a decrease in 2012 (Table 1 and

Figure 1). The 2012 mean trawl survey catch density estimate (from 67 tows) was 80.0 t/km^3 ($\overline{D}_{CSR,2012}$), which corresponds to a biomass estimate of 40,176 t for the WCVI core region ($I_{CSR,2012}$), 8,312 t for inlet extrapolation ($I_{IE,2012}$) and 48,488 t for the two combined ($I_{CSR+IE,2012}$).

3.1.3. BC migration rates

Migration rates calculated from SS model population biomass estimates decreased from 2006 to 2010, increased somewhat for 2011, and decreased for 2012. Migration rates from AT survey population biomass estimates have comparable trends to those from SS model biomass estimates, except for 2006 and 2010, where migration rates from AT survey estimates were relatively lower and higher, respectively (Table 3, Figure 3). Two or three year rolling average migration rate estimates calculated from SS model population biomass estimates showed a decreasing trend from 2006-2008 to 2010-2012.

Multi-season average migration rate estimates for 2006-2012 were lower than corresponding rates for 2006-2011 (Tables 3 and 4). Average migration rates based on age 1+ SS model biomass estimates for 2006-2012 were 15.3% and 18.5% for the WCVI core region alone and with inlet extrapolation, respectively; when 2012 was excluded, migration rates were 17.2% and 20.7%, respectively. Average migration rates based on age 2+ SS model biomass estimates for 2006-2012 were 19.0% and 22.9% for the WCVI core region alone and with inlet extrapolation, respectively; when 2012 was excluded, rates were 21.5% and 25.9%, respectively.

Multi-season average migration rates based on AT survey biomass estimates for ranged from 19.1% to 26.5% for the WCVI core region alone and with inlet extrapolation, respectively; when 2012 was excluded, rates were 25.3% and 30.5%, respectively.

3.1.4. BC length and age trends

Collectively, the range in fork lengths for most sardines sampled in 2012 from BC waters was 19-26 cm, with a mean of approximately 23 cm, a peak at 21-22 cm and a secondary peak at ~ 23-24 cm (Figures 4 and 5). Age estimates of randomly sampled fish from 11 survey tows ranged from approximately 1 to 10 years (Figure 5). Out of the 259 fish aged from 2012 trawl survey samples, approximately 30% were estimated to have two annuli and 15% were estimated to have three annuli, therefore representing relatively high frequencies of the 2009 and 2010 year classes.

3.1.5. Fishery exploitation

3.1.5.1. BC

Most annual BC sardine fishery TACs and all landings were higher in 2009-2012 compared to 2002-2008 (Table 5, Figure 6). For 2002-2008, BC fishery TACs ranged from 5,040-19,800 t, whereas the range in TACs for 2009-2012 was 18,196 to 27,279 t. For 2002-2008, BC fishery landings ranged from ~1,000-10,435 t, whereas the range in landings for 2009- 2012 landings was 5,334-22,223 t.

BC fishery regional TAC ratios ($p_{i,y}$) and exploitation rates ($u_{i,y}$) in 2006 and 2008-2012 were highly variable with relatively low rates for 2006 (<4%) and high rates for 2012 ($\geq$40%). Overall, regional exploitation rates ranged from <1% to 47.6%, with averages of 17.0% and 14.1% for the WCVI core survey region alone and with inlet extrapolation, respectively. Excluding 2012 estimates, the maximum estimate was 27.1% (for 2010) and averages for 2006 and 2008-2011 were 10.8% and 9.0%.

BC fishery population TAC ratios ($p_{BC,b,y}$) and exploitation rates ($u_{BC,b,y}$) were highest in 2012 (Tables 6 and 7, Figure 8). In general, rates for all SS biomass estimates showed increasing trends for 2008-2012 and rates representing biomass of older and larger fish were greater than for younger fish (Figure 8). Average exploitation rates from 2002-2012 SS population biomass estimates ranged from 1.0% to 2.0%, whereas averages from 2009-2012 ranged from 2.0% to 3.0% (Table 7).

Population TAC ratios and exploitation rates for AT survey biomass estimates had a high degree of variability but were generally comparable to or greater than estimates calculated from SS model biomass (Tables 6 and 7). Average population exploitation calculated from spring AT survey biomass estimates (2006, 2008, 2010-2012) was 3.2% and average population exploitation calculated from summer AT survey biomass estimates (2008 and 2012) was 3.6%.

3.1.5.2. The U.S. and BC fisheries combined

In 2012, the U.S. fishery TAC (109,409 t) and landed catch (99,552 t) were relatively high compared to 2008-2011 (which ranged from 46,745 - 72,039 t for TAC and catch combined) and most of the 2012 U.S. catch (>75%) was from Oregon and Washington (Table 5). The 2012 PNW catch (BC, Oregon and Washington combined) was 95,646 t, which was relatively high compared to earlier years (Table 5, Figure 9). Population exploitation rates in 2012 for the PNW, and for the BC and U.S. combined were also relatively high compared to previous years, and rates derived from SS age 1+ biomass estimates were 14.5% and 18.0%, respectively (Table 8, Figure 9).

3.2. HARVEST CONTROL RULE SCENARIOS

Based on time series trends in SS model population estimates from Hill et al. (2012), for each Type of HCR, hypothetical TAC ratios relating to age 1+ and 2+ population biomass estimates (p'_{1+} and p'_{2+}) had similar magnitudes and degrees of variability but values for age 2+ biomass were slightly higher (e.g. $\leq$ 0.05%). Similarly, for each Type of HCR, values across p'_{3+} and p'_{20+cm} were similar but both sets were generally higher than p'_{1+} and p'_{2+} values (e.g. $\geq$ 0.05%). Output depicting 2007-2012 fishing seasons is described below for the four types of HCRs. For Type 2, 3 and 4 HCRs, output depicting 1994-2012 trends is also included in Appendices F-H.

3.2.1. Type 1: $B_{1+,y-1}\ m_{i,1+,}\ x\ 0.15$ (includes status quo)

The greatest variability in hypothetical TACs and TAC ratios resulted from using previous year migration rate estimates ($m_{i,1+,y-1}$) and the least variability resulted from using constant values representing average migration rates for the six survey years ($\hat{m}_{i,2006\text{-}2012}$),Table 9 and Figure 10. Hypothetical TAC ratios for all types of age 1+ migration rate estimates showed decreasing trends over time but only results from previous year migration rates showed a notable increase for 2012. Means of hypothetical TACs ranged from 27,124 t ($\hat{m}_{CSR,1+,2006\text{-}2012}$) to 42,070 t ($m_{CSR+IE,1+,y-1}$). Means of TAC ratios for age 1+ and 2+ biomass ranged from 2.6% to 4.4% and means of ratios for age 3+ and 20+cm FL biomass ranged from 3.9% to 6.2%.

3.2.2. Type 2: $B_{1+,y-1}\ x\ h_{1+}$

As expected, hypothetical TACs and TAC ratios increased with increases in h_{1+} values. Hypothetical TACs decreased across the time series and their means ranged from 23,637 t (h_{1+}=2%) to 59,093 t (h_{1+}= 5%), Table 10 and Figure 11. Hypothetical TAC ratios for age 1+ and 2+ biomass had a slight overall increasing trend whereas ratios for age 3+ and 20+cm FL biomass did not have a consistent pattern. Means of TAC ratios for age 1+ and 2+ biomass ranged from 2.3% (h_{1+}=2%) to 6.5% (h_{1+}=5%) and means for age 3+ and 20+cm FL biomass ranged from 3.4% (h_{1+}=2%) to 9.0% (h_{1+}=5%).

3.2.3. Type 3: $(B_{1+,y-1} - 150{,}000)\ x\ h_{1+}$

Compared to Type 2 scenarios, the inclusion of the cutoff in Type 3 scenarios resulted in a reduction of hypothetical TACs and TAC ratios of approximately 9%. Means of hypothetical

TACs ranged from 20,641 t (h_{1+}=2%) to 51,603 t (h_{1+}=5%), Table 11 and Figure 12. Means of TAC ratios for age 1+ and 2+ biomass ranged from 2.0% (h_{1+}=2%) to 5.6% (h_{1+}=5%) and means for age 3+ and 20+cm FL biomass ranged from 3.0% (h_{1+}=2%) to 7.8% (h_{1+}=5%).

3.2.4. Type 4: constant annual TAC

All trends in hypothetical TAC ratios showed increases from 2007 to 2012 but trends for age 3+ and 20+cm FL biomass were less consistent. Means of TAC ratios for age 1+ and 2+ biomass ranged from 1.5% (*TAC'*= 15,000t) to 5.1% (*TAC'*=45,000t) and means for age 3+ and 20+cm FL biomass ranged from 2.2% (*TAC'* =15,000t) to 7.0% (*TAC'*= 45,000t), Table 12 and Figure 13.

4. DISCUSSION

4.1. STOCK STATUS AND TRENDS

The 2012 population biomass estimates from the SS assessment model, the AT surveys and the WCVI trawl survey were relatively low and indicated a declining population trend. Collectively, regional and population biomass estimates indicate that the California Current sardine population biomass and migration to BC have decreased relative to 2011 and earlier years.

Across all years, most sardine biomass observed in BC waters consisted of fish that were at least 20 cm but survey and fishery samples from some years (e.g. 1999, 2002, 2004, 2005 and 2010) were comprised of ≥10% shorter fish (Figures 4 and 5). These observations of interannual variability may result from several factors, such as reproduction and migration schedules, year class strength, population composition as well as overall population abundance.

There was considerable variation in estimates of migration among different age and size groups. Migration rates of age 3+ and 20+ cm FL were on average 1.5 to 2 times greater than estimates for age 1+ and age 2+ (Table 2). Average migration rates using AT survey biomass estimates were intermediate to those from SS model estimate.

Results from the SS assessment model indicate that the 2010 year class was relatively weak; however, preliminary results from the 2012 WCVI trawl survey indicate there was a relatively large proportion (30%) of the number of fish from the 2010 year class (Figure 5). The detection of age 2 and age 3 fish in the 2012 WCVI survey samples may indicate that the 2009 and 2010 year classes were at moderately high levels.

During the time when sardines generally begin their northward migration off northern California to BC, oceanographic conditions were relatively cool during the spring of 2012 suggesting northern sardine migration was delayed. The relatively low WCVI trawl survey sardine catch densities observed in BC waters in 2012 may be in part due to oceanographic conditions before and during the timing of the survey.

4.2. EXPLOITATION

BC regional and population-level sardine exploitation rates increased, especially from 2011 to 2012 and in the PNW. Landings from BC were relatively stable from 2010 to 2012 and landings from the U.S. increased (~50,000t) from 2011 to 2012 (Figure 6, Table 5). Although estimates of population exploitation presented in this report exclude landings from Ensenada (Mexico), Ensenada landings were reported to be relatively stable from 2008 to 2012 with a slight decrease from 2011 to 2012.

Exploitation rates of sardine in BC waters have been affected by several factors. For example, during 2002-2008, exploitation rates were limited by fishery management measures and low fishing effort. For the 2009 season, several management changes occurred, including an increase in the HCR's estimates of age 1+ migration rate (DFO 2009b). During 2009-2012, the mean of TACs (22,644 t) and landings (19,569 t), were considerably higher than means for 2002-2012 and reflected increases in fishing effort associated with developed markets. Based on age 1+ and 2+ SS model population estimates, exploitation rates indicate that up to ~ 3% of the adult population biomass was annually harvested in BC waters and TAC ratios indicate that up to ~ 4% was allowed to be harvested. These estimates may be useful for future management considerations.

Interannual variability in regional sardine exploitation rates in BC waters during 2006 and 2008-2012 was partly due to the use of an HCR with varying migration rates, as demonstrated by Type 1 HCRs. However, the high 2012 TAC ratios and exploitation rate estimates ($\geq$ 40%) was largely due to a relatively high population biomass estimate used in the 2012 BC fishery HCR equation ($B_{1+,2011}$= 988,385 t, Hill et al. 2011) compared to age 1+ biomass estimates used for previous years (e.g. 537,173 to 702,024 t, DFO 2009b, 2010, 2011b). Also associated with the relatively high 2012 BC regional TAC ratio and exploitation rate estimates was a Type 1 HCR age 1+ migration rate estimate of 18.4% (DFO 2012b) and uncertainty associated with the 2012 BC biomass estimates.

Most 2012 BC sardine fishery harvests occurred in August and September (Appendix B) when favourable sardine habitat conditions were observed off northern Washington and BC (Appendices J-L) which was after the WCVI trawl survey. Excluding 2012 survey estimates, TAC ratios and regional exploitation rates for BC waters in 2006 and 2008-2011 were less than or equal to 28% (Tables 6 and 7).

Harvest control rules and population exploitation rates for sardine and pelagic forage fish populations vary widely among countries and exploitation can reach up to 50%. Harvest rates of herring range from 10% to 27% in many northern hemisphere countries (Funk and Rowell 1995, Stick and Lindquist 2009, DFO 2011, ICES 2012, California Fish and Game Commission 2012, Thynes et al. 2012). Less complex harvest control rules that have been used for pelagic forage fish stocks include constant fishing mortality rates (e.g. using a constant annual harvest rate fraction), a constant fishing mortality in combination with a limit reference point below which fishing ceases, and, constant annual harvest amounts (constant yield). Management may also include size limits, gear, area or seasonal restrictions. Pikitch et al. (2012) concluded that constant yield and constant fishing mortality are the least sustainable fishing strategies among the ones they compared for harvesting forage fish. South Australia uses a simple conservative management approach with a minimum biomass and exploitation rate strategy, outlined in their Ecologically Sustainable Management Plan with an intended harvest rate of <20% (Ward et al. 2008). Chile uses a target annual harvest rate of 33% (as suggested by Patterson 1992) to manage stocks of small pelagic fishes. In the Benguela Current System (South Africa, Nambia and Angola), a limit reference of 33% and a target reference of 18% are used for sardine, anchovy, and herring (Fairweather et al. 2006). Japan does not use target harvest rates directly, but recently developed a feedback strategy which attempts to limit fishing mortality at 38% (Hurtado-Ferro et al. 2010). Japan's fishery management recognizes the environmental control of sardine and other small pelagic fishes (anchovy, mackerel, saury), with increased fishing limits when climate and ocean conditions result in high stock abundance. Mexico does not use target or reference exploitation rates, or TACs; rather, they have a minimum size limit, which is rarely met, to reduce recruitment overfishing. In the Adriatic Sea, a target of 29% is used for sardine and anchovy with a limit reference of 33% (Cingolani et al. 2005). In the eastern Mediterranean a target 40% is used for round sardine (Salem et al. 2010). Oman uses a target

33% for small pelagics, including the Indian oil sardine (Al-Anbouri et al. 2011). Canada's current exploitation of Pacific Sardine may be considered relatively conservative compared to fishing policies on other temperate pelagic forage fish species and/or stocks in other countries.Extensive research has focussed on determining appropriate harvest and exploitation rates of forage fish to provide sustainable fishing opportunities while protecting marine ecosystems. Forage fish populations are sensitive to environmental forcing and experience considerable inter-annual, decadal- and multi-decadal scale variability (Baumgartner et al. 1992, Schwartzlose et al. 1999, McFarlane et al. 2002, Valdes et al. 2008). Appropriate management strategies for Pacific Sardine, should incorporate their life history attributes, population variability, behaviour and role in the ecosystem.

According to Patterson (1992), on a single species basis, the preferred objective for managing highly variable stocks is to maintain biomass above a predetermined critical level. Similarly, King and McFarlane (2003) suggested that opportunistic strategists, such as Pacific Sardine, should be managed to maintain a "critical spawning biomass", below which fishing should cease. This critical stock biomass may be determined as some level of the unexploited stock size, such as the lowest historical stock size at which no negative effect on recruitment has been observed, or as the biomass which produced high levels of recruitment (i.e. the stock size from which a stock can rebound (Patterson 1992). Patterson (1992) also recommended an exploitation rate (proportion of total mortality caused by fishing) of 0.4 for temperate and sub-tropical small pelagic fish as a "rather conservative" measure that would likely allow for stock increases or decreases. He found that any stock that has a mean long term exploitation history (e.g. 10 years) of 0.5 was likely to suffer a stock decline (73-85% of the time), and that an exploitation rate of 0.3 almost always allowed increases or recoveries.

DFO's Fishery Decision-making Framework for single species management employs harvest control rules with limit, target, and upper stock reference points. Reference points are often based on unfished biomass estimates and/or biomass estimates based on maximum sustainable yield (MSY) theory. Fishing mortality is adjusted based on the current stock status, with no fishing removals when the stock is below the lower limit reference point and reduced fishing removals when the stock is below the upper stock reference point. These principles were also recommended as the best management strategy by Pikitch et al. (2012) for forage fish, including Pacific Sardine. Currently there is not enough information to define a set of reference points and status zones for use in setting TACs for the BC sardine fishery, especially because the stock is transboundary and fished in two other countries. Thus the best harvest framework for the California Current sardine population would be a coordinated one involving the three countries. In addition to single species exploitation and harvest rates, forage requirements by predators that depend on forage species should be considered as described in DFO's forage fish policy (DFO 2009c).

Schooling behaviour in fish, such as sardine, is a predator avoidance strategy that can lead to depensation in stock recruit relationships (Clark 1974). A consequence of depensation can be population collapses through direct and indirect effects of increased fishing effort resulting in unstable population states or reduced population resilience to environmental variations (Clark 1974). The catchability of schooling fish, such as sardines, is inversely related to stock abundance; therefore, these fish are vulnerable (i.e., visible) even at low abundances (MacCall 1976). Management strategies should consider the need for caution at low population abundances.

4.3. HARVEST CONTROL RULES

Goals of this paper included describing and considering HCRs related to management objectives outlined in Section 1.4 and which do not rely on information from an annual trawl survey. The trends associated with HCR scenarios were entirely deterministic and did not account for effects of fishing at hypothetical TAC levels, sources of error, natural variability, uncertainty or risk associated with varying management decisions. Also, none of the four types of HCRs are fully consistent with the DFO Fishery Decision-making Framework (DMF) and incorporation of the Precautionary Approach policy since they do not apply reference points that distinguish stock status zones for healthy, cautious and critical states (DFO 2009a). However, some pros and cons (based mainly on costs, logistics and some management objectives) of each type of HCR have been identified and are summarized below.

Type 1 HCRs with annually varying age 1+ migration rates provide Fisheries Management with annual updates that are intended to be responsive to annual changes in sardine abundance. This type of HCR requires annual estimates of regional biomass and migration, which is dependent on annual observations from the WCVI trawl survey. Survey biomass estimates may be biased during years of unusual environmental conditions or due to mismatches in survey and migration timing. Varying migration rate estimates in HCRs resulted in higher inter-annual variability in hypothetical TAC and TAC ratios relative to Type 2 and 3 HCRs, although using a constant migration rate estimate reduced this variability.

Type 2 HCRs, using a fraction of the previous season SS assessment model age 1+ biomass estimate are intended to enable harvest allowances to be responsive to changes in the population abundance. Provided that the fraction is not excessively high, this type of HCR could address some population ecosystem considerations by removing a constant proportion of the population, rather than a constant amount of biomass. Also, Type 2 HCRs do not require information from an annual WCVI trawl survey.

Type 3 HCRs, using a fraction of the previous season SS assessment model age 1+ biomass estimate and a cutoff (150,000t), have the same attributes as Type 2 HCRs but are slightly more precautionary at equal harvest rate fractions, especially when sardine population biomass is low. This is because the effect of the cutoff is to reduce allowable harvests as population biomass levels decrease (Appendix I).

Type 4 HCRS, with constant annual TACs, are intended to provide stability to fishers. Type 4 HCRs do not require information from an annual WCVI trawl survey. Also, Type 4 HCRs do not require or rely on results from the U.S. SS assessment model. The disadvantages of Type 4 HCRs however, outweigh the benefits. Constant TAC amounts do not respond to changes in stock size and do not account for ecosystem processes or environmental conditions. These HCRs are not precautionary and during declines in sardine abundance may result in over exploitation (e.g. increasing exploitation rates with decreasing stock biomass as demonstrated in Figure 13). Furthermore, during periods of increasing abundance, a constant TAC could result in a loss of potential harvest opportunities. The South Australia sardine fishery applies a constant TAC but one that is considered very conservative (e.g. $\leq$ 30,000 t) and which was determined after a thorough evaluation of ecosystem dynamics associated with the stock (Ward et al. 2008).

Output from Type 2 and 3 HCR scenarios suggests that the use of previous season age 1+ biomass estimates results in relatively low variability in age 2+ TAC ratios, although trends and scales were similar to those of age 1+ ratios (Tables 10, 11, Figures 11, 12, Appendices F, G). The relatively low variability in age 2+ TAC ratios is due to their correlation with previous season estimates of age 1+ biomass used in the HCR equations (representing the same cohort groups). Therefore if age 1+ biomass from a previous season is a good measure of the next season's age 2+ biomass and if fishing (in BC) targets age 2+, then the use of a previous season age 1+ estimate may be warranted, especially in the absence of other reliable measures or forecasts of age 2+biomass for the coming fishing season. However if and when the fishery targets age 3+ or 20+cm FL (due to migratory abundance or fishing markets), age 1+ estimates would not be expected to have the same forecasting strength. Hypothetical scenarios for Type 2 and 3 HCRs also demonstrate how certain older cohort groups may be vulnerable to exploitation pressure in a given fishing season when the SS model age 1+ biomass for the previous season is relatively high and consisting mostly of age 1 recruitment (e.g. Appendix F and G depictions of the 2005 fishing season).

4.4. HARVEST OPTIONS AND ADVICE

Of the four types of HCRs described in this paper, Types 2 and 3 are believed to be superior to Types 1 and 4. We recommend that a Type 1 HCR with an annually varying migration rate estimate be discontinued for use in providing harvest advice for the BC fishery because it introduces variability to the TACs, TAC ratios, potential population exploitation rates and possibly regional exploitation rates (Table 9, Figure 10) and is dependent on WCVI trawl survey data. Type 4 is advised against because it is not sensitive to variations in population or regional biomass and is the least precautionary at low biomass levels.

Of the four types of HCRs described in this report, Type 3 is the only one that has a parameter that acts like a reference limit through the inclusion of the cutoff value of 150,000t, because as the population biomass estimate approaches this value, fishing allowances decrease and ultimately cease (Appendix I). Therefore, Type 3 HCRs adhere to some principles of the DFO Fishery Decision Making Framework. It is unclear, however, if this cutoff would reduce risks of the population approaching undefined cautious or critical levels.

Harvest options for the 2013 fishing season resulting from the recent status quo HCR are 10,091 t or 12,168 t, based on three-year average migration rate estimates for the WCVI core region alone ($\bar{m}_{CSR,1+,2012}$ =10.2%) and with inlet extrapolation ($\bar{m}_{CSR+IE,1+,2012}$ =12.3%), respectively (Table 13). Table 13 also presents harvest options from applying alternate age 1+ migration rates ($m_{i,1+,2012}$ and, $\hat{m}_{i,1+,\,2006\text{-}2012}$). Harvest options for the 2013 fishing season from applying Type 2 and 3 HCRs at h_{1+} fractions ranging from 0.03 to 0.05 are shown in Table 14.

4.5. UNCERTAINTY

A summary of some of the key issues related to uncertainty that should be considered when setting sardine harvest allowances in BC waters is presented here.

Due to information constraints, no measures of uncertainty, risk or performance in the context of DFO's Fishery Decision-making Framework can be included with any of the harvest options. An important consideration for choosing a harvest rate (e.g. h_{1+}, h_{BC}) is that at larger fractions, TACs and exploitation rates will increase and be more variable

Removing a varying age 1+ migration rate estimate in a BC fishery HCR enables the population biomass estimate to have more influence on population and BC regional exploitation rates. Whether age 1+ biomass estimates in HCRs outperform other measures of population biomass for their ability to meet conservation and management objectives or to predict migration is not known.

The recent BC sardine data time series is relatively short (e.g. 16 separate years of fishery and/or survey observations combined) and the reported information from six years of night trawl surveys is limited in terms of depicting trends in migration and evaluating the relative performance of varying HCRs.

There is uncertainty associated with how biomass has been estimated for BC waters. Sources of uncertainty include: 1) the timing of the trawl survey and its ability to represent biomass in BC waters, 2) survey vessel and trawl gear effects on sardine catchability, 3) the assumption that the average sardine densities are representative of the upper 30m of the water column in the survey region and inlet areas. These topics have been discussed and documented in previous reviews (DFO 2009d, DFO 2012a, DFO 2012b).

There has been debate over possible detrimental effects of each country (the U.S., Mexico and Canada) independently setting harvest allowances (e.g. DFO 2012c). Concerns include the possibility that the collective harvest rate of the three countries may exceed harvest rates applied in individual countries. Other concerns include unknown effects on stock structure and reproductive capacity from targeting younger and smaller components of the population (e.g. from southern California) versus older and larger components of the population (e.g. from Washington, Oregon and BC).

There is uncertainty in the Stock Synthesis population biomass estimates due to model assumptions. Individual biomass indices integrated into the Stock Synthesis assessment model have relatively high interannual variability and the Stock Synthesis assessment model tends to smooth out sampling variance (Hill et al 2011, 2012). Interannual changes to modeling methods can result in substantial changes to both total biomass and biomass of different age and size components of the population, which directly affects HCR outcomes. Key sources of uncertainty in Stock Synthesis outputs include uncertainties in:1) biomass indices, 2) mortality estimates, 3) representation of length and age relationships, and 4) recruitment estimates.

Estimates of recruitment of recent year classes have relatively high uncertainty since there are fewer years of observations on these cohorts. Also, observations may be confounded by fishery selectivity and aspects of spatial distribution.

4.6. FUTURE CONSIDERATIONS

A limited set of HCRs was included in this report and other types should be considered and evaluated for possible future implementation, especially HCRs that are more consistent with the DFO Fishery Decision-making Framework. Candidate HCRs should be evaluated by conservation and fishery performance measures, which ideally would include characterization of population and ecosystem responses to varying harvest strategies using a risk analysis simulation model. Additional research could be done to try to improve the characterization of migration rate estimates using information associated with population age and size structure of abundance and marine environmental conditions (e.g., as covariates). Improvements to model-based migration rate estimates may help characterize realized exploitation and be more informative for forecasting.

A management strategy evaluation (MSE) is one approach to inform and improve science advice regarding potential harvest strategies. Performance measures could be defined to generate output to evaluate the potential effect of specific HCRs. Zhang et al. (2013) described examples of successful measures of harvest strategies as ones that “result in high landings, low inter-annual variation in catch, high spawning stock biomass at the end of the management period, and high minimum spawning stock biomass during the management period”. These are similar to some of the principles of the work conducted by the Pacific Fishery Management Council in 1998 to determine the U.S.’s most recent HCR, but that earlier work did not extend to considering changes in regional and international fishing efforts. A more ambitious MSE could try to address concerns that the collective exploitation of the California Current sardine population exceeds those associated with regional conservation interests in Canadian, U.S., and Mexican waters. The best fisheries harvest framework for the California Current sardine population would be a coordinated one on an international scale.

If the standardized WCVI trawl survey was conducted every second or third year, efforts should be made to continue the collection of BC sardine biological data (survey and fishery samples) as well as ecological species associations and oceanographic data. The collection of fishery independent data is especially important if the fishery is concentrated in time and space and when markets encourage selection pressure for certain physical conditions (e.g. size, age, fat content) thus potentially biasing catch samples. Also, the surveys provide an important source of ecological observations associated with the species distribution and relative abundance, which fishery observations do not.

5. ACKNOWLEDGEMENTS

Key individuals who helped coordinate night trawl surveys and manage survey data include Vanessa Hodes, Jackie Detering, Bill Andrews and Christa Hrabok and many others who assisted in survey data collection. We also acknowledge the crews of the *W.E. Ricker* for their support during the surveys. Funding for the collection and processing of commercial catch samples and catch records has been provided by the Canadian Pacific Sardine Association and the First Nations Sardine Association. We also thank staff at *D&D Pacific Fisheries* for their role in the acquisition of commercial purse seine samples and data. In addition, *Larocque* relief funds covered some survey expenses. We thank Kevin Hill for providing results from Stock Synthesis (model configuration SSX6e). We also thank Sean MacConnachie for preparing sardine density maps and Rowan Haigh for helping with statistical weighting and plotting of trawl survey fork length observations.

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7. TABLES

Table 1. Sardine mean catch densities and biomass estimates for the west coast of Vancouver Island (WCVI) core survey region (CSR) and areas of inlet extrapolation (IE), including lower (LL) and upper (UL) limits for 90% confidence intervals for CSR sardine density and biomass estimates. Population biomass estimates from the Stock Synthesis model (ages 1+, 2+, 3+ and 20+cm fork length) or spring (sp) and summer (su) acoustic-trawl (AT) surveys are also shown (from Hill et al. 2012). Biomass is in tonnes.

Year	2006	2007	2008	2009	2010	2011	2012
WCVI core survey region trawl sampling							
Number of trawl tows	44	-	60	95	57	68	67
Proportion of tows with sardines	0.93	-	0.67	0.49	0.65	0.6	0.45
Mean sardine density (t/km^3)							
$\overline{D}_{CSR}$	759.9	-	420	378.3	163.2	301.0	80.0
$\overline{D}_{LL}$	496	-	224	242	70	194	29
$\overline{D}_{UL}$	1,055	-	662	531	277	440	143
Standard deviation	1148	-	1062	852	485	664.3	286.5
CV of the mean	0.23	-	0.33	0.23	0.39	0.27	0.43
WCVI core survey region biomass, representing 502.2 km^3							
I_{CSR}	381,622	-	210,924	189,982	81,959	151,162	40,176
I_{LL}	249,091	-	112,493	121,532	35,154	97,427	14,564
I_{UL}	529,821	-	332,456	266,668	139,109	220,968	71,815
WCVI inlets PFMA 20, 23-27 biomass, representing 31.4 km^3							
	23,861	-	13,188	11,879	5,124	9,451	2,512
Mainland inlets PFMA 7,8,9,10 and 12 biomass, representing 72.5 km^3							
	55,093	-	30,450	27,427	11,832	21,823	5,800
Sum of WCVI core survey region and inlet biomass, representing 606.1 km^3							
I_{CSR+IE}	460,575	-	254,562	229,288	98,916	182,436	48,488
Population biomass, components of Stock Synthesis Assessment							
B_{1+}	1,365,980	1,356,860	1,286,760	1,106,180	1,077,220	898,150	659,539
B_{2+}	934,945	1,196,960	1,069,290	994,623	830,996	839,872	620,550
B_{3+}	705,926	697,202	890,063	758,883	706,297	567,171	562,603
B_{20+cm}	574,372	702,601	772,178	730,831	654,250	577,097	501,044
Population biomass, acoustic-trawl surveys							
B_{ATsp}	1,947,063	-	751,075	-	357,006	493,672	469,480
B_{ATsu}	-	-	801,000	-	-	-	340,831

No WCVI survey in 2007; PFMA refers to DFO Pacific Fishery Management Area (see Appendix B).

Table 2. Summary statistics for 1993-2012 Stock Synthesis model (version X6e) sardine population biomass estimates for ages 1+, 2+, 3+ and 20+ cm fork length (from Hill et al. 2012).

	B_{1+}	B_{2+}	B_{2+}	B_{20+cm}
Mean	1,008,739	808,233	573,241	543,210

	B_{1+}	B_{2+}	B_{2+}	B_{20+cm}
Median	1,015,841	835,434	574,583	575,735
Min	507,320	307,639	171,128	175,593
Max	1,365,980	1,196,960	890,063	772,178
SD	249,747	237,565	200,465	166,571
CV	0.248	0.294	0.350	0.307

Table 3. Percent annual sardine migration to British Columbia (BC) based on ratios of BC biomass to population biomass resulting from the Stock Synthesis model or an Acoustic-Trawl survey (Hill et al. 2012). For each year, estimates for both the WCVI core survey region alone and with inlet extrapolation are shown (separated by a comma). Means of 2006, 2008 to 2012 migration rates are also included.

Year	2006	2008	2009	2010	2011	2012	$\hat{m}_{i,b,\ 2006\text{-}2012}$
Migration rates based on Stock Synthesis population estimates							
$m_{i,1+}$	27.9, 33.7	16.4, 19.8	17.2, 20.7	7.6, 9.2	16.8, 20.3	6.1, 7.4	15.3, 18.5
$m_{i,2+}$	40.8, 49.3	19.7, 23.8	19.1, 23.1	9.9, 11.9	18.0, 21.7	6.5, 7.8	19.0, 22.9
$m_{i,3+}$	54.1, 65.2	23.7, 28.6	25.0, 30.2	11.6, 14.0	26.7, 32.2	7.1, 8.6	24.7, 29.8
$m_{i,20+cm}$	66.4, 80.2	27.3, 33.0	26.0, 31.4	12.5, 15.1	26.2, 31.6	8.0, 9.7	27.7, 33.5
Migration rates based on Acoustic-Trawl survey estimates							
$m_{i,ATsp}$	19.6, 23.7	28.1, 33.9	-	23.0, 27.7	30.6, 37.0	8.6, 10.3	22.0, 26.5
$m_{i,ATsu}$	-	26.3, 31.8	-	-	-	11.8, 14.2	19.1, 23.0

Table 4. Two or three year average percent sardine migration to British Columbia (BC) based on ratios of BC biomass to population biomass resulting from the Stock Synthesis model or an Acoustic-Trawl survey (Hill et al. 2012). For each set of years, estimates for both the WCVI core survey region alone and with inlet extrapolation are shown (separated by a comma). Means of 2006, 2008 to 2011 migration rates are also included to consider the exclusion of 2012 results.

Years	2006, 2008	2008, 2009	2008-2010	2009-2011	2010-2012	$\hat{m}_{i,b,\ 2006\text{-}2011}$
Migration rates based on Stock Synthesis population estimates						
$\bar{m}_{i,1+}$	22.2, 26.8	16.8, 20.3	13.7, 16.6	13.9, 16.7	10.2, 12.3	17.2, 20.7
$\bar{m}_{i,2+}$	30.3, 36.5	19.4, 23.4	16.2, 19.6	15.7, 18.9	11.4, 13.8	21.5, 25.9
$\bar{m}_{i,3+}$	38.9, 46.9	24.4, 29.4	20.1, 24.3	21.1, 25.5	15.1, 18.3	28.2, 31.7
$\bar{m}_{i,20+cm}$	46.9, 56.6	26.7, 32.2	21.9, 26.5	21.6, 26.0	15.6, 18.8	31.7, 38.3
Migration rates based on Acoustic-Trawl survey estimates						
$\bar{m}_{i,ATsp}$	23.8, 28.8	NA	25.5, 30.8	26.8, 32.3	20.7, 25.0	25.3, 30.5
$\bar{m}_{i,ATsu}$	NA	NA	NA	NA	NA	NA

Table 5. Sardine fishery total allowable catch (TAC) and landings (tonnes) for British Columbia (BC), the west coast Vancouver Island (WCVI), the Pacific North Coast Integrated Management Area of BC (PNCIMA), the Pacific Northwest (PNW = Washington, Oregon and BC combined) and the United States (U.S.).

	BC		*WCVI	*PNCIMA	PNW	U.S.		BC + U.S.	
Year	TAC	Landings	Landings	Landings	Landings	TAC	Landings	TAC	Landings
2002	5,040	822	482	340	38,745	118,442	101,367	123,482	102,189
2003	9,000	1,006	1,006	0	37,868	110,908	74,599	119,908	75,605
2004	15,000	4,259	4,179	80	49,170	122,747	92,613	137,747	96,872
2005	15,200	3,266	595	2670	55,203	136,179	90,130	151,379	93,396
2006	13,500	1,558	0	1,558	41,305	118,937	90,776	132,437	92,334
2007	19,800	1,507	275	1,232	48,222	152,564	127,696	172,364	129,202
2008	12,491	10,435	5,670	4,765	39,810	89,093	87,175	101,584	97,610
2009	18,196	15,334	8,073	7,262	44,841	66,932	67,083	85,128	82,417
2010	23,166	22,223	18,911	3,312	55,456	72,039	66,891	95,205	89,114
2011	21,917	20,719	20,718	0	39,751	50,526	46,745	72,443	67,463
2012	27,279	19,129	19,129	0	95,646	109,409	99,552	136,688	118,681
Mean	16,417	9,114	7,185	1,929	49,638	104,343	85,875	120,760	94,989
Median	15,200	4,259	4,179	1,232	44,841	110,908	90,130	123,482	93,396
SD	6,483	8,686	8,375	2,381	16,516	31,193	21,534	29,853	17,691
CV	0.395	0.953	1.166	1.234	0.333	0.299	0.251	0.247	0.186
2009-2012									
Mean	22,640	19,351	16,708	2,644	58,923	74,727	70,068	97,366	89,419
Median	22,542	19,924	19,020	1,656	50,148	69,486	66,987	90,167	85,766
SD	3,745	2,961	5,813	3,452	25,341	24,876	21,850	27,820	21,505
CV	0.165	0.153	0.348	1.306	0.43	0.333	0.312	0.286	0.241

**WCVI= DFO Pacific Fishery Management Areas 20-27 and 121-127 (see Appendix B)*

**PNCIMA =Pacific North Coast DFO Pacific Fishery Management Areas 6-12*

Table 6. British Columbia (BC) sardine fishery total allowable catch (TAC) ratios (p) based on BC biomass for the west coast of Vancouver Island core survey region alone (CSR) and with inlet extrapolation (CSR+IE) or population biomass for components of SS model (ages 1+, 2+, 3+ or 20+cm fork length) and acoustic-trawl (AT) spring (sp) and summer (su) surveys.

	BC TAC : BC biomass		BC TAC : Population biomass					
Year	p_{CSR}	p_{CSR+IE}	$p_{BC,1+}$	$p_{BC,2+}$	$p_{BC,3+}$	$p_{BC,20+cm}$	$p_{BC,ATsp}$	$p_{BC,ATsu}$
2002	-	-	0.006	0.007	0.008	0.008	-	-
2003	-	-	0.014	0.015	0.019	0.019	-	-
2004	-	-	0.015	0.035	0.038	0.041	-	-
2005	-	-	0.014	0.017	0.054	0.038	-	-
2006	0.035	0.029	0.010	0.014	0.019	0.024	0.007	-
2007	-	-	0.015	0.017	0.028	0.028	-	-
2008	0.059	0.049	0.010	0.012	0.014	0.016	0.017	0.016
2009	0.096	0.079	0.016	0.018	0.024	0.025	-	-
2010	0.283	0.234	0.022	0.028	0.033	0.035	0.065	-
2011	0.145	0.120	0.024	0.026	0.039	0.038	0.044	-
2012	0.679	0.563	0.041	0.044	0.048	0.054	0.058	0.080
Mean	0.216	0.179	0.017	0.021	0.029	0.030	0.038	0.048
Median	0.120	0.100	0.015	0.017	0.028	0.028	0.044	0.048
SD	0.243	0.201	0.010	0.011	0.015	0.013	0.025	0.046
CV	1.125	1.125	0.566	0.519	0.494	0.445	0.666	0.953
2009-2012								
Mean	0.301	0.249	0.026	0.029	0.036	0.038	0.056	NA
Median	0.214	0.177	0.023	0.027	0.036	0.037	0.058	NA
SD	0.264	0.219	0.011	0.011	0.01	0.012	0.010	NA
CV	0.879	0.881	0.423	0.379	0.278	0.316	0.179	NA

Table 7. British Columbia (BC) sardine fishery exploitation rates (u), based on the ratios of BC catch landings to BC biomass for the west coast of Vancouver Island core survey region alone (CSR) and with inlet extrapolation (CSR+IE) or to population biomass for components of the SS model (ages 1+, 2+, 3+ or 20+cm fork length) and acoustic-trawl (AT) spring (sp) and summer (su) surveys.

	BC landings: BC biomass		BC landings : Population biomass					
Year	u_{CSR}	u_{CSR+IE}	$u_{BC,1+}$	$u_{BC,2+}$	$u_{BC,3+}$	$u_{BC,20+cm}$	$u_{BC,ATsp}$	$u_{BC,ATsu}$
2002	-	-	0.001	0.001	0.001	0.001	-	-
2003	-	-	0.002	0.002	0.002	0.002	-	-
2004	-	-	0.004	0.01	0.011	0.012	-	-
2005	-	-	0.003	0.004	0.012	0.008	-	-
2006	0.004	0.003	0.001	0.002	0.002	0.003	0.001	-
2007	-	-	0.001	0.001	0.002	0.002	-	-
2008	0.049	0.041	0.008	0.01	0.012	0.014	0.014	0.013
2009	0.081	0.067	0.014	0.015	0.020	0.021	-	-
2010	0.271	0.225	0.021	0.027	0.031	0.034	0.062	-
2011	0.137	0.114	0.023	0.025	0.037	0.036	0.042	-
2012	0.476	0.395	0.029	0.031	0.034	0.038	0.041	0.056
Mean	0.170	0.141	0.010	0.012	0.015	0.016	0.032	0.036
Median	0.109	0.090	0.004	0.010	0.012	0.012	0.042	0.036
SD	0.176	0.146	0.011	0.012	0.014	0.015	0.025	0.032
CV	1.038	1.038	1.071	0.986	0.917	0.942	0.763	0.900
2009-2012								
Mean	0.241	0.200	0.022	0.025	0.031	0.033	0.049	NA
Median	0.204	0.170	0.022	0.026	0.034	0.035	0.043	NA
SD	0.176	0.146	0.007	0.007	0.007	0.008	0.012	NA
CV	0.728	0.728	0.318	0.280	0.226	0.242	0.245	NA

Table 8. Sardine population exploitation rates (u) for the Pacific Northwest (PNW = BC, Washington and Oregon combined), for BC and the U.S. combined and for total allowable catch population ratios (p) for BC and the U.S. combined. Values are proportions of population biomass estimates resulting from the SS model (ages 1+, 2+ and 3+ or 20+cm fork length) or from acoustic-trawl (AT) spring (sp) and summer (su) surveys.

	Pacific Northwest landings : Population biomass						**BC+U.S : Population biomass**	
Year	$u_{PNW,1+}$	$u_{PNW,2+}$	$u_{PNW,3+}$	$u_{PNW,20+cm}$	$u_{PNW,ATsp}$	$u_{PNW,ATsu}$	$p_{BC+US,1+}$	$u_{BC+US,1+}$
2002	0.045	0.053	0.058	0.062	-	-	0.142	0.118
2003	0.060	0.063	0.079	0.079	-	-	0.189	0.119
2004	0.050	0.114	0.124	0.133	-	-	0.141	0.099
2005	0.050	0.060	0.198	0.139	-	-	0.137	0.084
2006	0.030	0.044	0.059	0.072	0.021	-	0.097	0.068
2007	0.036	0.040	0.069	0.069	-	-	0.127	0.095
2008	0.031	0.037	0.045	0.052	0.053	0.050	0.079	0.076
2009	0.041	0.045	0.059	0.061	-	-	0.077	0.075
2010	0.051	0.067	0.079	0.085	0.155	-	0.088	0.083
2011	0.044	0.047	0.070	0.069	0.081	-	0.081	0.075
2012	0.145	0.154	0.170	0.191	0.204	0.281	0.207	0.180
Mean	0.053	0.066	0.092	0.092	0.103	0.165	0.124	0.098
Median	0.045	0.053	0.07	0.072	0.081	0.165	0.127	0.084
SD	0.032	0.036	0.05	0.043	0.075	0.163	0.045	0.033
CV	0.601	0.548	0.547	0.473	0.731	0.989	0.361	0.332
2009-2012								
Mean	0.056	0.063	0.077	0.082	0.119	NA	0.113	0.104
Median	0.048	0.057	0.074	0.077	0.121	NA	0.085	0.079
SD	0.021	0.022	0.018	0.023	0.037	NA	0.063	0.052
CV	0.711	0.657	0.540	0.595	0.424	NA	0.554	0.499

Table 9. Type 1 harvest control rule input parameters and resultant output. A) Input parameters: SS model age 1+ biomass ($B_{1+,\,y-1}$), regional harvest rate fraction (h_{BC}), and age 1+migration rates for the west coast of Vancouver Island core survey region alone (CSR) and with inlet extrapolation (CSR+IE). B) Resultant output: hypothetical total allowable catch (TAC' in tonnes) and the ratio of TAC' and SS model population biomass estimates (p') for ages 1+, 2+, 3+ or 20+cm fork length.

A) Input parameters	Biomass (tonnes)	Harvest fraction	Age 1+ migration rate $m_{i,1+,y-1}$		$\overline{m}_{i,1+,y-1}$		$\widehat{m}_{i,1+,2006-2012}$	
Fishing year-1	$B_{1+,\,y-1}$	h_{BC}	CSR	CSR+IE	CSR	CSR+IE	CSR	CSR+IE
2006	1,365,980	0.15	0.279	0.337	-	-	0.153	0.185
2007	1,356,860	0.15	*0.279	0.337	-	-	0.153	0.185
2008	1,286,760	0.15	0.164	0.198	0.222	0.268	0.153	0.185
2009	1,106,180	0.15	0.172	0.207	0.168	0.203	0.153	0.185
2010	1,077,220	0.15	0.076	0.092	0.137	0.166	0.153	0.185
2011	898,150	0.15	0.168	0.203	0.139	0.167	0.153	0.185

* Due to lack of 2007 trawl survey, 2006 estimates were used for 2007

B) Resultant output	Year	$m_{i,1+,y-1}$ CSR	$m_{i,1+,y-1}$ CSR+IE	$\overline{m}_{i,1+,y-1}$ CSR	$\overline{m}_{i,1+,y-1}$ CSR+IE	$\widehat{m}_{i,1+,2006-2012}$ CSR	$\widehat{m}_{i,1+,2006-2012}$ CSR+IE
TAC'	2007	57,166	69,050	-	-	31,349	37,906
	2008	56,785	68,589	-	-	31,140	37,653
	2009	31,654	38,217	42,849	51,728	29,531	35,708
	2010	28,539	34,347	27,876	33,683	25,387	30,696
	2011	12,280	14,866	22,137	26,823	24,722	29,893
	2012	22,633	27,349	18,726	22,499	20,613	24,924
	Mean	34,843	42,070	27,897	33,683	27,124	32,797
	Median	30,097	36,282	25,006	30,253	27,459	33,202
	SD	18,373	22,192	10,659	12,881	4,265	5,157
	CV	0.527	0.528	0.382	0.382	0.157	0.157
p'_{1+}	2007	0.042	0.051	-	-	0.023	0.028
	2008	0.044	0.053	-	-	0.024	0.029
	2009	0.029	0.035	0.039	0.047	0.027	0.032
	2010	0.026	0.032	0.026	0.031	0.024	0.028
	2011	0.014	0.017	0.025	0.030	0.028	0.033
	2012	0.034	0.041	0.028	0.034	0.031	0.038
	Mean	0.032	0.038	0.029	0.036	0.026	0.032
	Median	0.031	0.038	0.027	0.033	0.025	0.031
	SD	0.011	0.013	0.006	0.008	0.003	0.004
	CV	0.344	0.349	0.207	0.222	0.115	0.125
p'_{2+}	2007	0.048	0.058	-	-	0.026	0.032
	2008	0.053	0.064	-	-	0.029	0.035
	2009	0.032	0.038	0.043	0.052	0.030	0.036
	2010	0.034	0.041	0.034	0.041	0.031	0.037
	2011	0.015	0.018	0.026	0.032	0.029	0.036
	2012	0.036	0.044	0.030	0.036	0.033	0.040
	Mean	0.036	0.044	0.033	0.040	0.030	0.036
	Median	0.035	0.043	0.032	0.038	0.030	0.036
	SD	0.013	0.016	0.007	0.009	0.002	0.003
	CV	0.361	0.370	0.212	0.225	0.067	0.083
p'_{3+}	2007	0.082	0.099	-	-	0.045	0.054
	2008	0.064	0.077	-	-	0.035	0.042
	2009	0.042	0.050	0.056	0.068	0.039	0.047
	2010	0.040	0.049	0.039	0.048	0.036	0.043
	2011	0.022	0.026	0.039	0.047	0.044	0.053
	2012	0.040	0.049	0.033	0.040	0.037	0.044
	Mean	0.048	0.058	0.042	0.051	0.039	0.047
	Median	0.041	0.050	0.039	0.047	0.038	0.046
	SD	0.021	0.026	0.010	0.012	0.004	0.005
	CV	0.438	0.440	0.238	0.235	0.103	0.106

B) Resultant output		$m_{i,1+,y-1}$		$\overline{m}_{i,1+,y-1}$		$\widehat{m}_{i,1+,2006-2012}$	
	Year	CSR	CSR+IE	CSR	CSR+IE	CSR	CSR+IE
p'_{20+cm}	2007	0.081	0.098	-	-	0.045	0.054
	2008	0.074	0.089	-	-	0.040	0.049
	2009	0.043	0.052	0.059	0.071	0.040	0.049
	2010	0.044	0.052	0.043	0.051	0.039	0.047
	2011	0.021	0.026	0.038	0.046	0.043	0.052
	2012	0.045	0.055	0.037	0.045	0.041	0.050
	Mean	0.051	0.062	0.044	0.053	0.041	0.050
	Median	0.044	0.054	0.040	0.049	0.041	0.049
	SD	0.022	0.027	0.010	0.012	0.002	0.002
	CV	0.431	0.431	0.227	0.226	0.049	0.040

Table 10. Type 2 harvest control rule output resulting from varying the population harvest rate fraction (h_{1+}), showing hypothetical total allowable catch (TAC' in tonnes) and the ratio of TAC' and SS model population biomass estimates (p') for ages 1+, 2+, 3+ or 20+cm fork length.

	h_{1+}	0.02	0.025	0.03	0.035	0.04	0.045	0.05
	Year							
TAC'	2007	27,320	34,150	40,979	47,809	54,639	61,469	68,299
	2008	27,137	33,922	40,706	47,490	54,274	61,059	67,843
	2009	25,735	32,169	38,603	45,037	51,470	57,904	64,338
	2010	22,124	27,655	33,185	38,716	44,247	49,778	55,309
	2011	21,544	26,931	32,317	37,703	43,089	48,475	53,861
	2012	17,963	22,454	26,945	31,435	35,926	40,417	44,908
	Mean	23,637	29,546	35,456	41,365	47,274	53,184	59,093
	Median	23,929	29,912	35,894	41,876	47,859	53,841	59,824
	SD	3,717	4,646	5,575	6,505	7,434	8,363	9,292
	CV	0.157	0.157	0.157	0.157	0.157	0.157	0.157
p'_{1+}	2007	0.020	0.025	0.030	0.035	0.040	0.045	0.050
	2008	0.021	0.026	0.032	0.037	0.042	0.047	0.053
	2009	0.023	0.029	0.035	0.041	0.047	0.052	0.058
	2010	0.021	0.026	0.031	0.036	0.041	0.046	0.051
	2011	0.024	0.030	0.036	0.042	0.048	0.054	0.060
	2012	0.027	0.034	0.041	0.048	0.054	0.061	0.068
	Mean	0.023	0.028	0.034	0.040	0.045	0.051	0.057
	Median	0.022	0.028	0.033	0.039	0.044	0.050	0.055
	SD	0.003	0.003	0.004	0.005	0.005	0.006	0.007
	CV	0.119	0.119	0.119	0.119	0.119	0.119	0.119
p'_{2+}	2007	0.023	0.029	0.034	0.040	0.046	0.051	0.057
	2008	0.025	0.032	0.038	0.044	0.051	0.057	0.063
	2009	0.026	0.032	0.039	0.045	0.052	0.058	0.065
	2010	0.027	0.033	0.040	0.047	0.053	0.060	0.067
	2011	0.026	0.032	0.038	0.045	0.051	0.058	0.064
	2012	0.029	0.036	0.043	0.051	0.058	0.065	0.072
	Mean	0.026	0.032	0.039	0.045	0.052	0.058	0.065
	Median	0.026	0.032	0.039	0.045	0.052	0.058	0.064
	SD	0.002	0.002	0.003	0.003	0.004	0.004	0.005
	CV	0.076	0.076	0.076	0.076	0.076	0.076	0.076
p'_{3+}	2007	0.039	0.049	0.059	0.069	0.078	0.088	0.098
	2008	0.030	0.038	0.046	0.053	0.061	0.069	0.076
	2009	0.034	0.042	0.051	0.059	0.068	0.076	0.085
	2010	0.031	0.039	0.047	0.055	0.063	0.070	0.078
	2011	0.038	0.047	0.057	0.066	0.076	0.085	0.095
	2012	0.032	0.040	0.048	0.056	0.064	0.072	0.080
	Mean	0.034	0.043	0.051	0.060	0.068	0.077	0.085
	Median	0.033	0.041	0.049	0.058	0.066	0.074	0.082
	SD	0.004	0.005	0.005	0.006	0.007	0.008	0.009
	CV	0.107	0.107	0.107	0.107	0.107	0.107	0.107
p'_{20+cm}	2007	0.039	0.049	0.058	0.068	0.078	0.087	0.097
	2008	0.035	0.044	0.053	0.062	0.070	0.079	0.088
	2009	0.035	0.044	0.053	0.062	0.070	0.079	0.088
	2010	0.034	0.042	0.051	0.059	0.068	0.076	0.085
	2011	0.037	0.047	0.056	0.065	0.075	0.084	0.093
	2012	0.036	0.045	0.054	0.063	0.072	0.081	0.090
	Mean	0.036	0.045	0.054	0.063	0.072	0.081	0.090
	Median	0.036	0.044	0.053	0.062	0.071	0.080	0.089
	SD	0.002	0.002	0.003	0.003	0.004	0.004	0.005
	CV	0.050	0.050	0.050	0.050	0.050	0.050	0.050

Table 11. Type 3 harvest control rule output resulting from varying the population harvest rate fraction (h_{1+}), in association with a cutoff of 150,000 tonnes, showing hypothetical total allowable catch (TAC' in tonnes) and the ratio of TAC' and SS model population biomass estimates (p') for ages 1+, 2+, 3+ or 20+cm fork length.

	h_{1+}	0.02	0.025	0.03	0.035	0.04	0.045	0.05
	Year							
TAC'	2007	24,316	30,395	36,475	42,554	48,633	54,712	60,791
	2008	24,126	30,158	36,190	42,221	48,253	54,284	60,316
	2009	22,715	28,394	34,073	39,751	45,430	51,109	56,788
	2010	19,113	23,891	28,669	33,447	38,226	43,004	47,782
	2011	18,570	23,212	27,855	32,497	37,140	41,782	46,424
	2012	15,006	18,757	22,508	26,260	30,011	33,763	37,514
	Mean	20,641	25,801	30,962	36,122	41,282	46,442	51,603
	Median	20,914	26,142	31,371	36,599	41,828	47,056	52,285
	SD	3,697	4,621	5,546	6,470	7,394	8,318	9,243
	CV	0.179	0.179	0.179	0.179	0.179	0.179	0.179
p'_{1+}	2007	0.018	0.022	0.027	0.031	0.036	0.040	0.045
	2008	0.019	0.023	0.028	0.033	0.038	0.042	0.047
	2009	0.021	0.026	0.031	0.036	0.041	0.046	0.051
	2010	0.018	0.022	0.027	0.031	0.035	0.040	0.044
	2011	0.021	0.026	0.031	0.036	0.041	0.046	0.052
	2012	0.023	0.028	0.034	0.040	0.045	0.051	0.057
	Mean	0.020	0.025	0.030	0.034	0.039	0.044	0.049
	Median	0.020	0.025	0.029	0.034	0.039	0.044	0.049
	SD	0.002	0.002	0.003	0.003	0.004	0.004	0.005
	CV	0.097	0.097	0.097	0.097	0.097	0.097	0.097
p'_{2+}	2007	0.020	0.025	0.030	0.036	0.041	0.046	0.051
	2008	0.023	0.028	0.034	0.040	0.045	0.051	0.056
	2009	0.023	0.029	0.034	0.040	0.046	0.051	0.057
	2010	0.023	0.029	0.035	0.040	0.046	0.052	0.058
	2011	0.022	0.028	0.033	0.039	0.044	0.050	0.055
	2012	0.024	0.030	0.036	0.042	0.048	0.054	0.060
	Mean	0.022	0.028	0.034	0.039	0.045	0.051	0.056
	Median	0.023	0.028	0.034	0.040	0.045	0.051	0.057
	SD	0.001	0.002	0.002	0.002	0.003	0.003	0.003
	CV	0.056	0.056	0.056	0.056	0.056	0.056	0.056
p'_{3+}	2007	0.035	0.044	0.052	0.061	0.070	0.078	0.087
	2008	0.027	0.034	0.041	0.047	0.054	0.061	0.068
	2009	0.030	0.037	0.045	0.052	0.060	0.067	0.075
	2010	0.027	0.034	0.041	0.047	0.054	0.061	0.068
	2011	0.033	0.041	0.049	0.057	0.065	0.074	0.082
	2012	0.027	0.033	0.040	0.047	0.053	0.060	0.066
	Mean	0.030	0.037	0.045	0.052	0.059	0.067	0.074
	Median	0.029	0.036	0.043	0.050	0.057	0.064	0.071
	SD	0.003	0.004	0.005	0.006	0.007	0.008	0.009
	CV	0.116	0.116	0.116	0.116	0.116	0.116	0.116
p'_{20+cm}	2007	0.035	0.043	0.052	0.061	0.069	0.078	0.087
	2008	0.031	0.039	0.047	0.055	0.062	0.070	0.078
	2009	0.031	0.039	0.047	0.054	0.062	0.070	0.078
	2010	0.029	0.037	0.044	0.051	0.058	0.066	0.073
	2011	0.032	0.040	0.048	0.056	0.064	0.072	0.080
	2012	0.030	0.037	0.045	0.052	0.060	0.067	0.075
	Mean	0.031	0.039	0.047	0.055	0.063	0.071	0.078
	Median	0.031	0.039	0.047	0.055	0.062	0.070	0.078
	SD	0.002	0.002	0.003	0.003	0.004	0.004	0.005
	CV	0.060	0.060	0.060	0.060	0.060	0.060	0.060

Table 12. Type 4 harvest control rule output resulting from varying hypothetical constant total allowable catch (TAC' in tonnes) showing the ratio of TAC' and SS model population biomass estimates (p') for ages 1+, 2+, 3+ or 20+cm fork length.

TAC'		**15,000**	**20,000**	**25,000**	**30,000**	**35,000**	**40,000**	**45,000**
	Year							
p'_{1+}	2007	0.011	0.015	0.018	0.022	0.026	0.029	0.033
	2008	0.012	0.016	0.019	0.023	0.027	0.031	0.035
	2009	0.014	0.018	0.023	0.027	0.032	0.036	0.041
	2010	0.014	0.019	0.023	0.028	0.032	0.037	0.042
	2011	0.017	0.022	0.028	0.033	0.039	0.044	0.050
	2012	0.023	0.030	0.038	0.045	0.053	0.060	0.068
	Mean	0.015	0.020	0.025	0.030	0.035	0.040	0.045
	Median	0.014	0.018	0.023	0.027	0.032	0.037	0.041
	SD	0.004	0.006	0.007	0.009	0.010	0.011	0.013
	CV	0.286	0.286	0.286	0.286	0.286	0.286	0.286
p'_{2+}	2007	0.013	0.017	0.021	0.025	0.029	0.033	0.038
	2008	0.014	0.019	0.023	0.028	0.033	0.037	0.042
	2009	0.015	0.020	0.025	0.030	0.035	0.040	0.045
	2010	0.018	0.024	0.030	0.036	0.042	0.048	0.054
	2011	0.018	0.024	0.030	0.036	0.042	0.048	0.053
	2012	0.024	0.032	0.040	0.048	0.056	0.064	0.072
	Mean	0.017	0.023	0.028	0.034	0.040	0.045	0.051
	Median	0.016	0.022	0.027	0.033	0.038	0.044	0.049
	SD	0.004	0.005	0.007	0.008	0.010	0.011	0.012
	CV	0.242	0.242	0.242	0.242	0.242	0.242	0.242
p'_{3+}	2007	0.022	0.029	0.036	0.043	0.050	0.057	0.065
	2008	0.017	0.022	0.028	0.034	0.039	0.045	0.051
	2009	0.020	0.026	0.033	0.040	0.046	0.053	0.059
	2010	0.021	0.028	0.035	0.043	0.050	0.057	0.064
	2011	0.026	0.035	0.044	0.053	0.062	0.071	0.079
	2012	0.027	0.035	0.044	0.053	0.062	0.071	0.080
	Mean	0.022	0.029	0.037	0.044	0.051	0.059	0.066
	Median	0.021	0.029	0.036	0.043	0.050	0.057	0.064
	SD	0.004	0.005	0.006	0.008	0.009	0.010	0.011
	CV	0.173	0.173	0.173	0.173	0.173	0.173	0.173
p'_{20+cm}	2007	0.021	0.028	0.036	0.043	0.050	0.057	0.064
	2008	0.019	0.026	0.032	0.039	0.045	0.052	0.058
	2009	0.021	0.027	0.034	0.041	0.048	0.055	0.062
	2010	0.023	0.031	0.038	0.046	0.053	0.061	0.069
	2011	0.026	0.035	0.043	0.052	0.061	0.069	0.078
	2012	0.030	0.040	0.050	0.060	0.070	0.080	0.090
	Mean	0.023	0.031	0.039	0.047	0.055	0.062	0.070
	Median	0.022	0.030	0.037	0.044	0.052	0.059	0.066
	SD	0.004	0.005	0.007	0.008	0.009	0.011	0.012
	CV	0.169	0.169	0.169	0.169	0.169	0.169	0.169

Table 13. Type 1 harvest control rule estimated biomass and harvest options (in tonnes) for the 2013 British Columbia sardine fishery.

Pacific Sardine population age 1+ biomass estimate SS X6e Semester 1 (for July 2012, Hill et al. 2012)			659,539
Type 1 HCR scenario	1a	1b	1c
Migration rate	$m_{i,1+,y-1}$	$\overline{m}_{i,1+,y-1}$	$\widehat{m}_{i,1+,2006\text{-}2012}$
WCVI CSR	6.1%	10.2%	15.3%
WCVI CSR +IE	7.4%	12.3%	18.5%
2013 BC biomass forecast			
WCVI CSR	40,232	67,273	100,909
WCVI CSR +IE	48,806	81,123	122,015
Regional harvest rate (h_{BC})	15%	15%	15%
Harvest options			
WCVI CSR	6,035	10,091	15,136
WCVI CSR +IE	7,321	12,168	18,302

Table 14. Type 2 and 3 harvest control rule estimated biomass and harvest options (in tonnes) for the 2013 British Columbia sardine fishery based on and varying population harvest rates from 3 to 5%.

Pacific Sardine population age 1+ biomass estimate SS X6e Semester 1 (for July 2012, Hill et al. 2012)			659,539
Harvest rate (h_{1+})	3%	4%	5%
Type 2: Harvest option without cutoff	19,786	26,382	32,977
Cutoff	150,000		
Type 3: Harvest option with cutoff	15,286	20,382	25,477

The cutoff matches the U.S. cutoff.

8. FIGURES

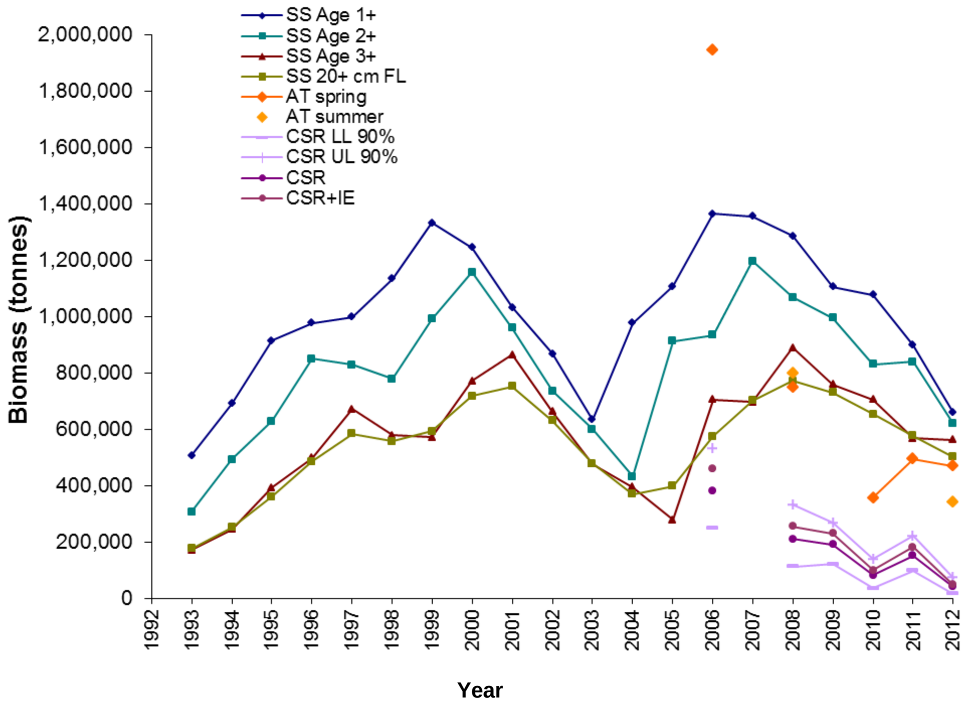


Figure 1. Sardine population and British Colombia biomass estimates. Population estimates are from Stock Synthesis (SS) model (version 6eX) representing July status and from acoustic-trawl (AT) surveys (Hill et al. 2012). British Columbia estimates are for the west coast of Vancouver Island core survey region alone (CSR) and with inlet extrapolation (CSR+IE). Lower (LL) and upper (UL) limits for 90% confidence intervals for core survey region biomass estimates are also included.

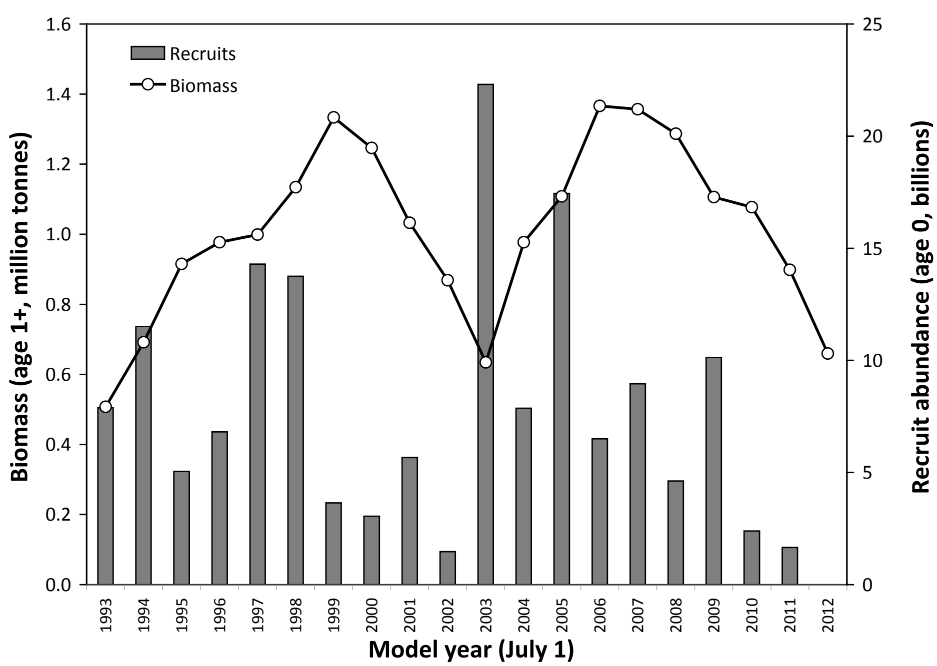
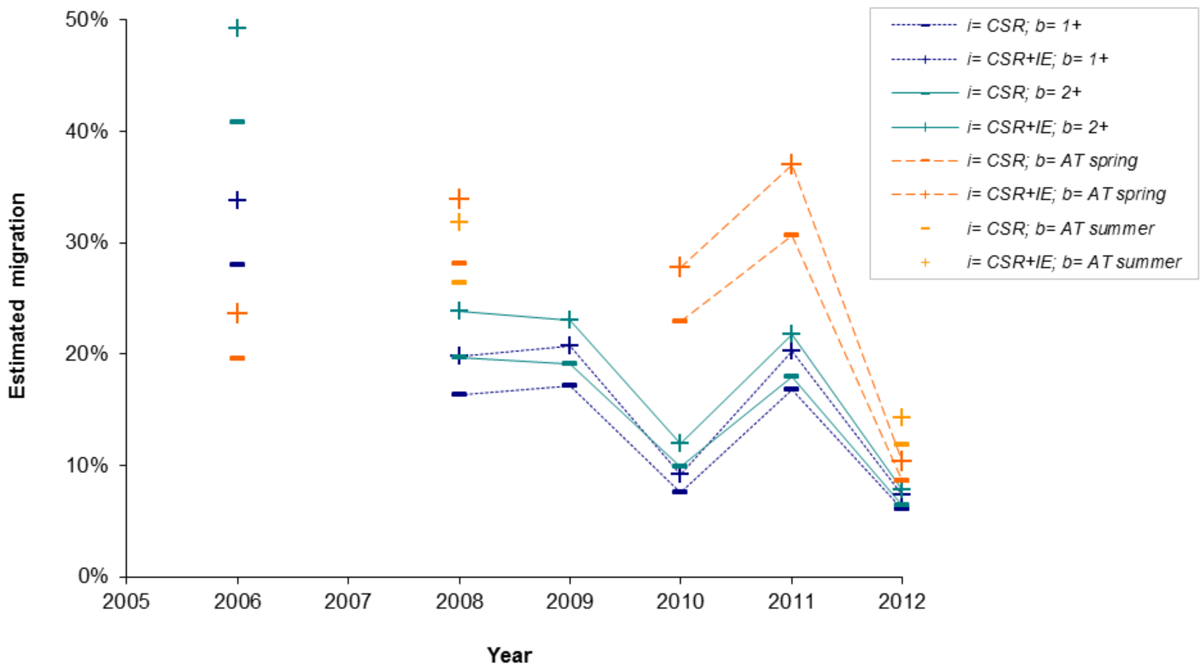


Figure 2. Stock Synthesis estimates of sardine recruitment by year class (bars represent number of fish) for the model year (July 1 – June 30th) and age 1+ biomass estimates for 1993-2012 (Hill et al. 2012).

A)



B)

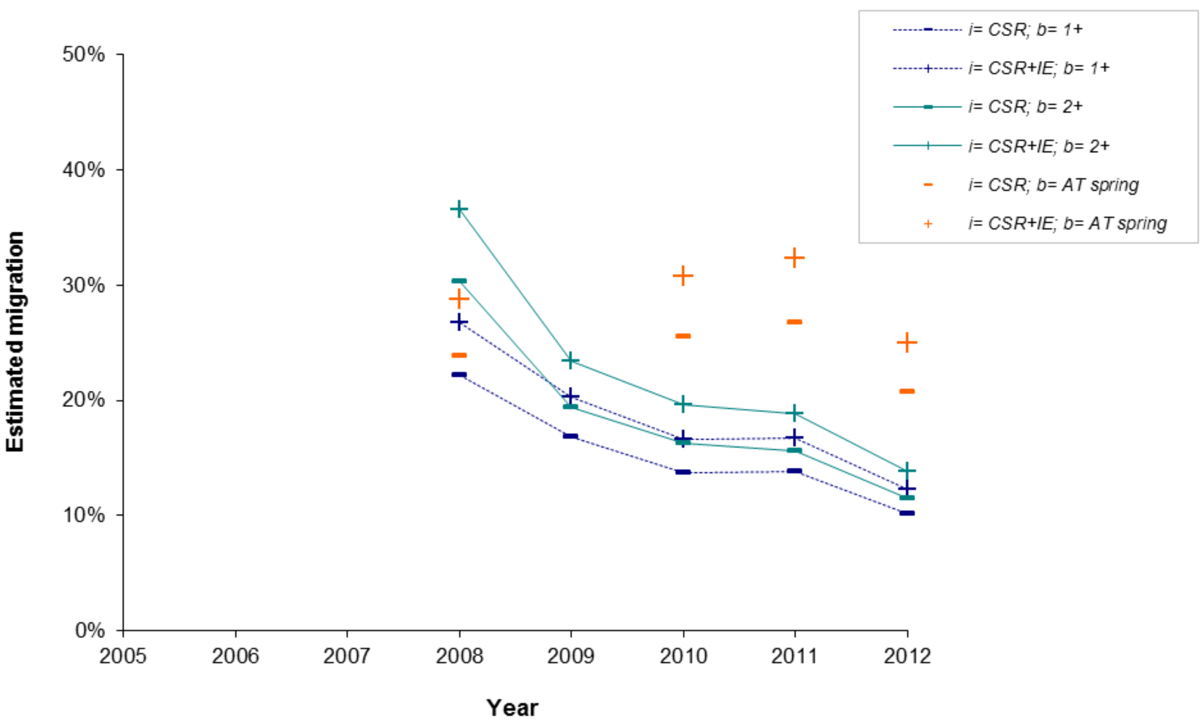


Figure 3. Sardine migration rate estimates based on the ratio of biomass for the west coast of Vancouver Island core survey region alone (i=CSR) or the CSR with inlet extrapolation (i=CSR+IE) to a type b population biomass estimate (for SS model age 1+ or 2+ or from an AT survey). Panel A: Annual estimates for 2006, 2008-2012. Panel B: Estimates of two or three-year averages.

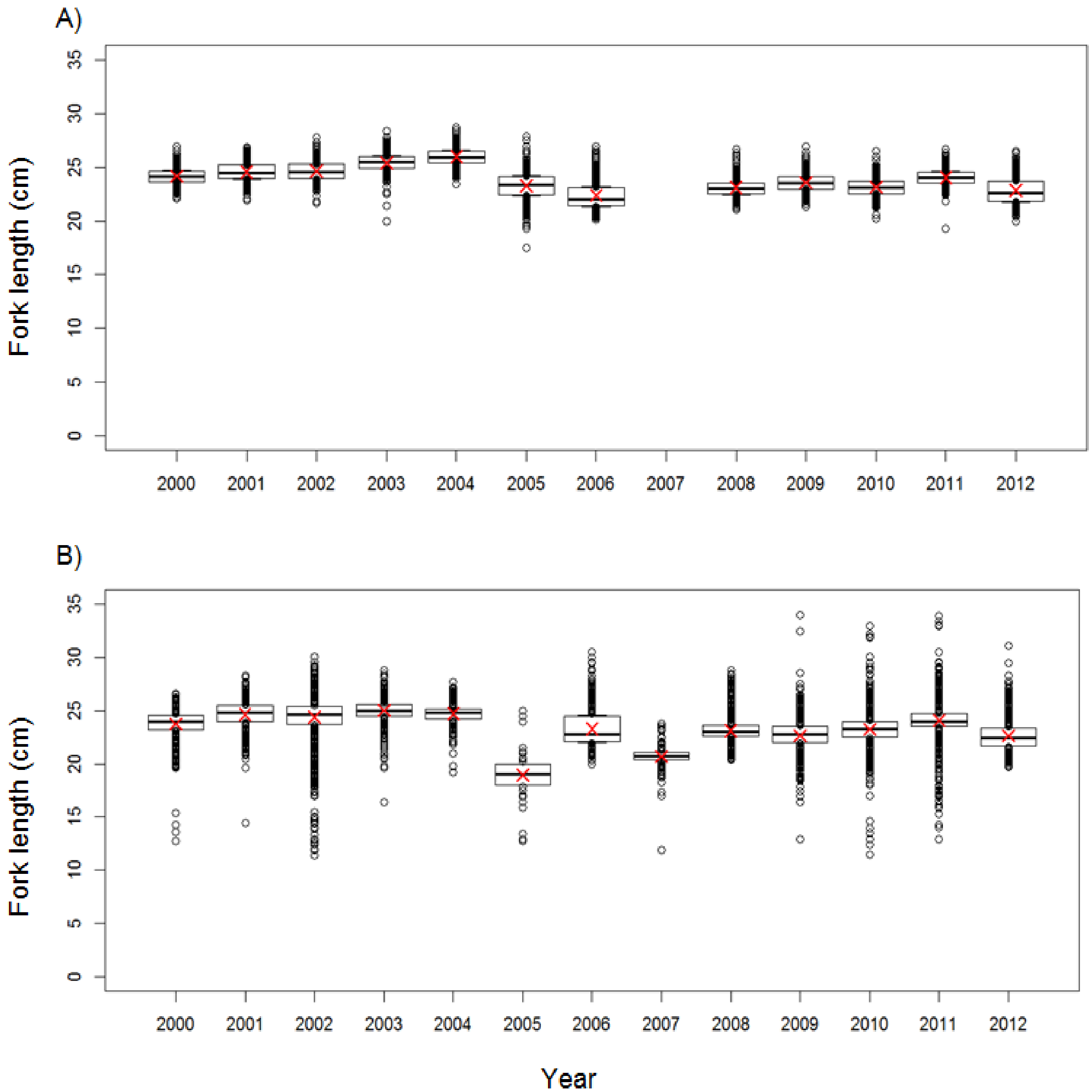


Figure 4. Sardine fork length distributions observed in British Columbia waters by year. Panel A: From summer research trawl surveys and statistically weighted by sardine catch density of the trawl tow (no 2007 survey). Panel B: From sardine fishery catch samples. Boxes encompass 50% of observations, medians are horizontal lines within boxes and means are red exes.

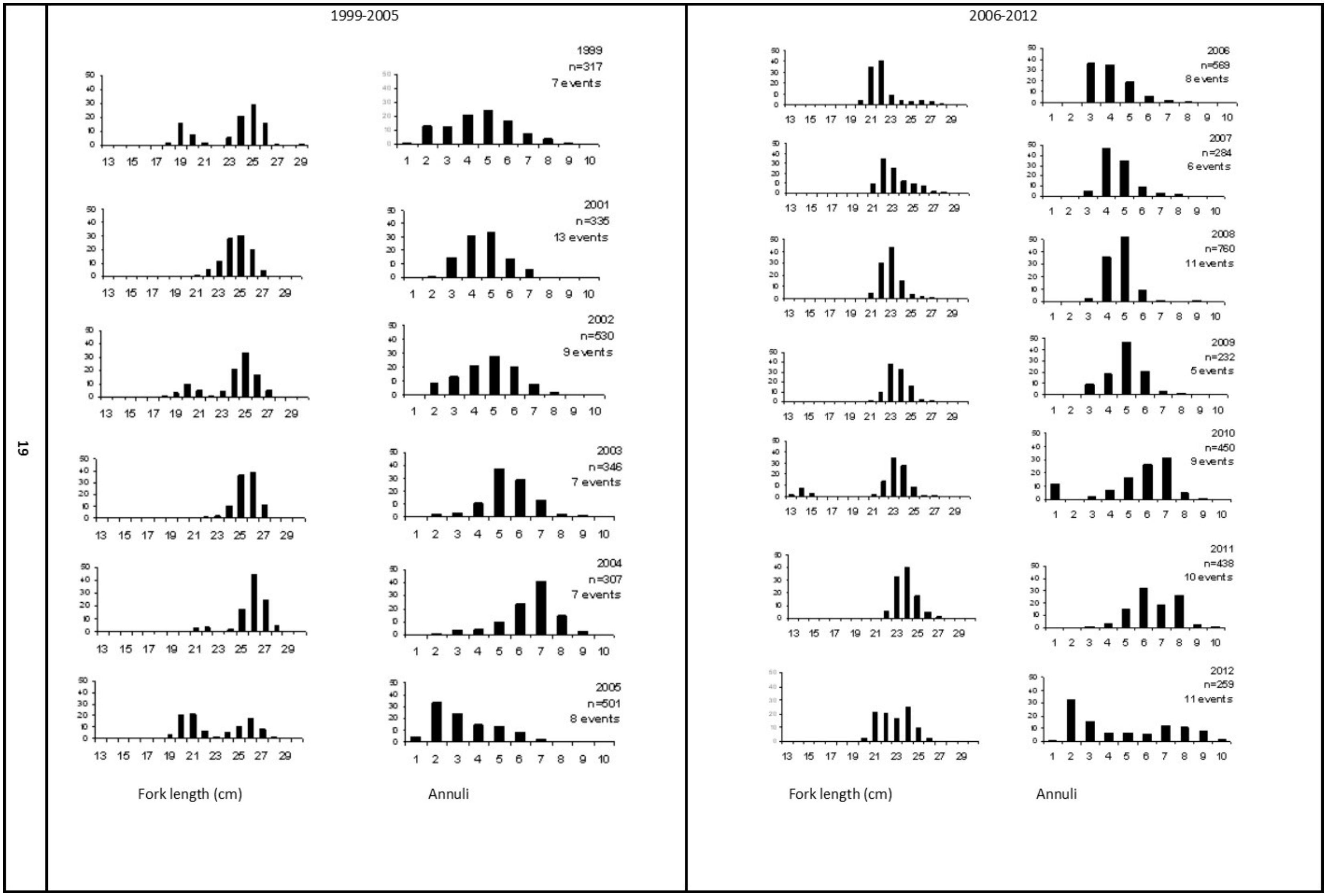


Figure 5. Sardine fork length and age frequencies (percent of number of fish) from pooled random samples collected from 1999 to 2012. Annuli counts (age estimates) represent minimum number of years detected through analysing otolith bands. Years 2001 and 2004 include both seine fishery and research trawl samples and 2007 includes seine fishery samples only. All other years represent research trawl samples.

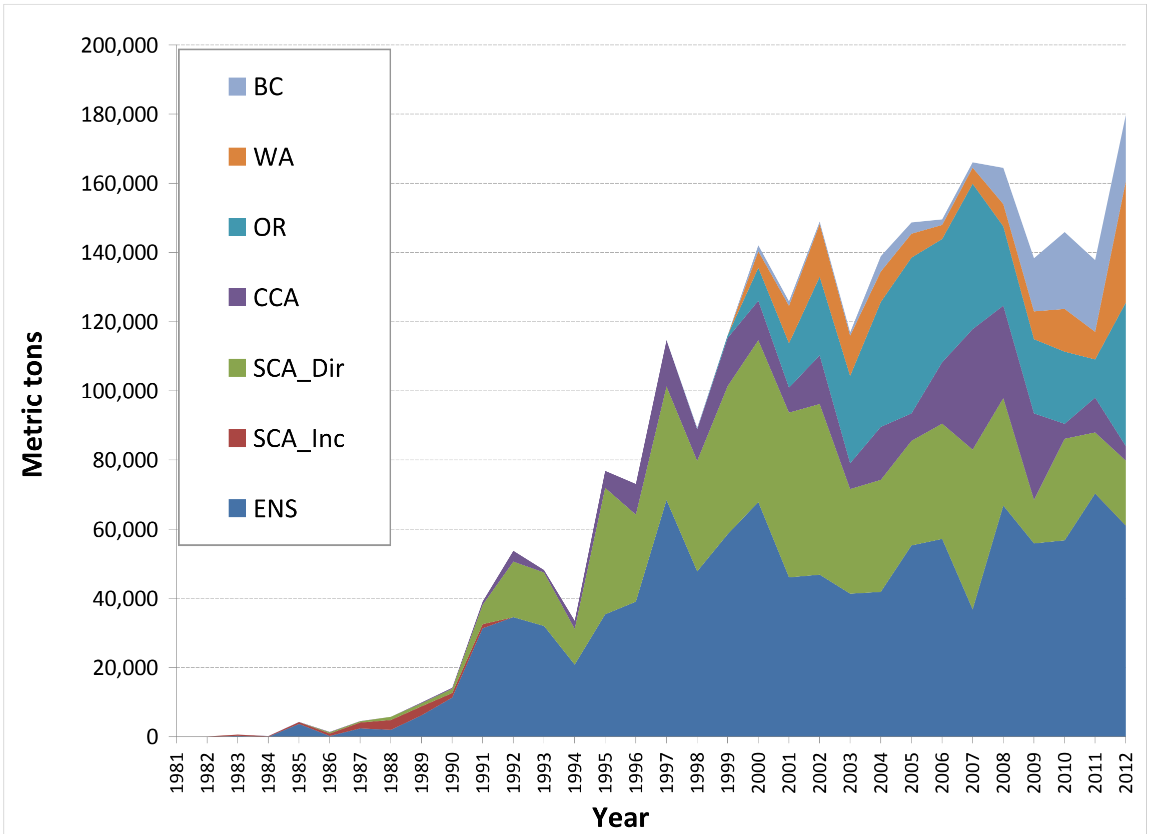


Figure 6. Sardine landings by fishing region and calendar year (from K.Hill pers comm and Hill et al. 2012).

Legend: BC= British Columbia; WA= Washington state; OR= Oregon state; CCA = central California; SCA_Dir and SCA_Inc = southern California directed and incidental fishing, respectively; ENS = Ensenada (Baja Mexico).

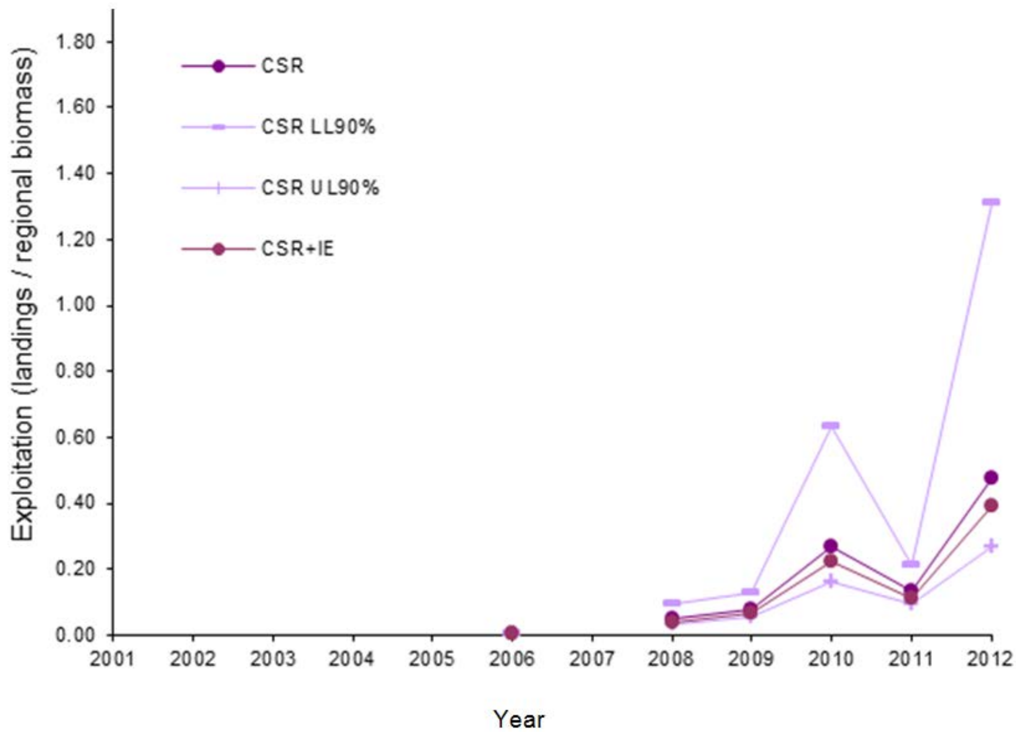


Figure 7. Regional estimates of sardine fishery exploitation in British Columbia waters based on the ratio of landings to biomass estimates for the west coast of Vancouver Island core survey region alone (CSR) and the CSR with inlet extrapolation (CSR+IE). Lower (LL) and upper (UL) limits for 90% confidence intervals for core survey region estimates are also included.

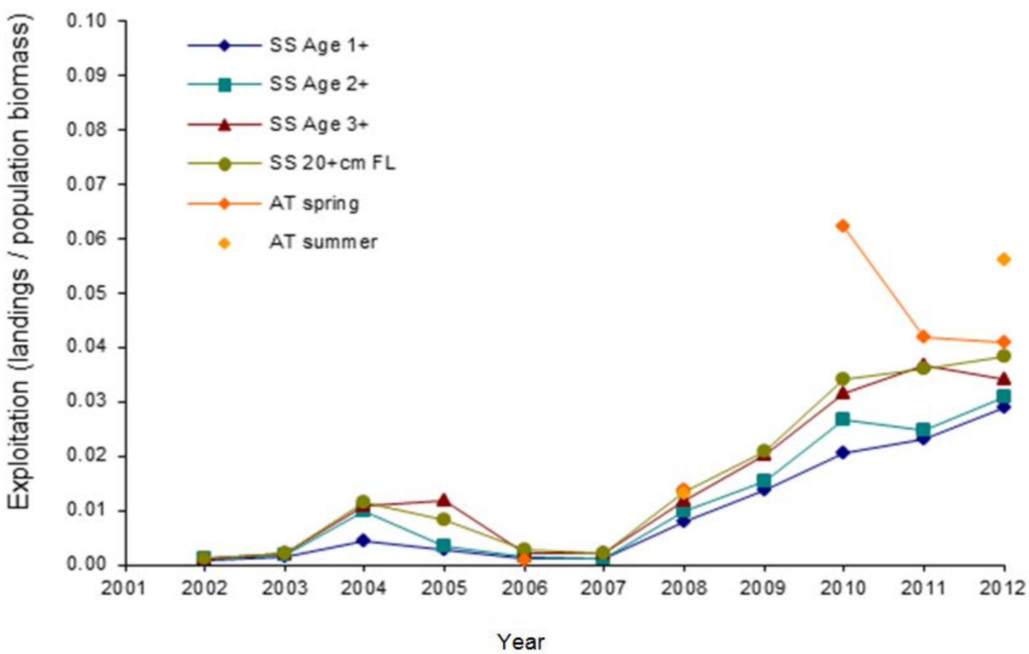


Figure 8. Estimates of British Columbia sardine fishery population exploitation based on the ratio of landings to population biomass estimates from SS model (ages 1+, 2+, 3+ or 20+cm fork length, for 2002-2012) or from acoustic-trawl (AT) surveys (2006, 2008, 2010-2012).

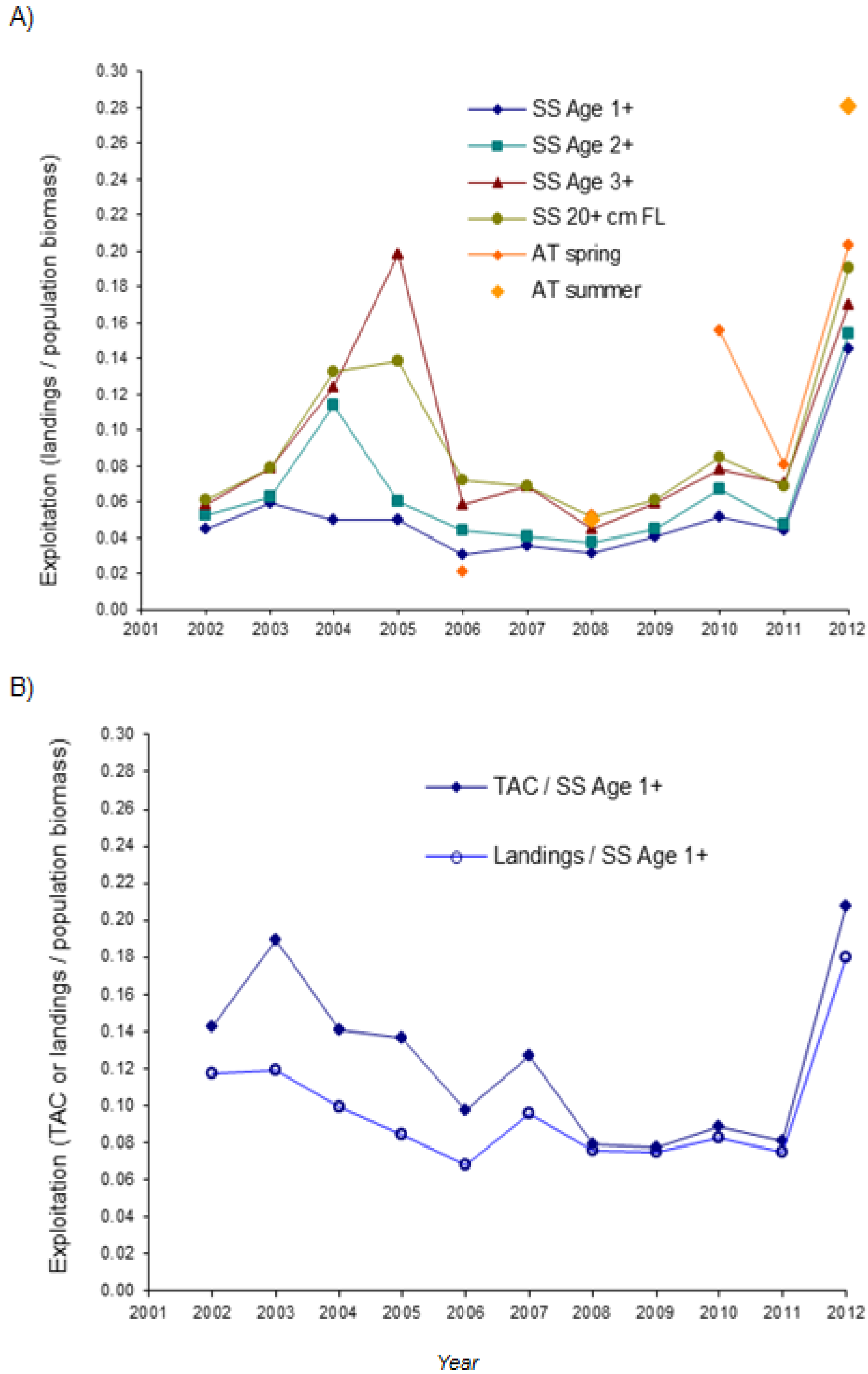


Figure 9. Panel A: Estimates of Pacific Northwest (British Columbia, Washington and Oregon combined) sardine fishery population exploitation from SS model biomass estimates (ages 1+, 2+, 3+ or 20+cm fork length, for 2002-2012) or from acoustic-trawl (AT) survey biomass estimates (2006, 2008, 2010-2012). Panel B: Estimates of British Columbia and U.S. combined population TAC ratios and population exploitation for 2002-2012 based on SS model age 1+ population biomass.

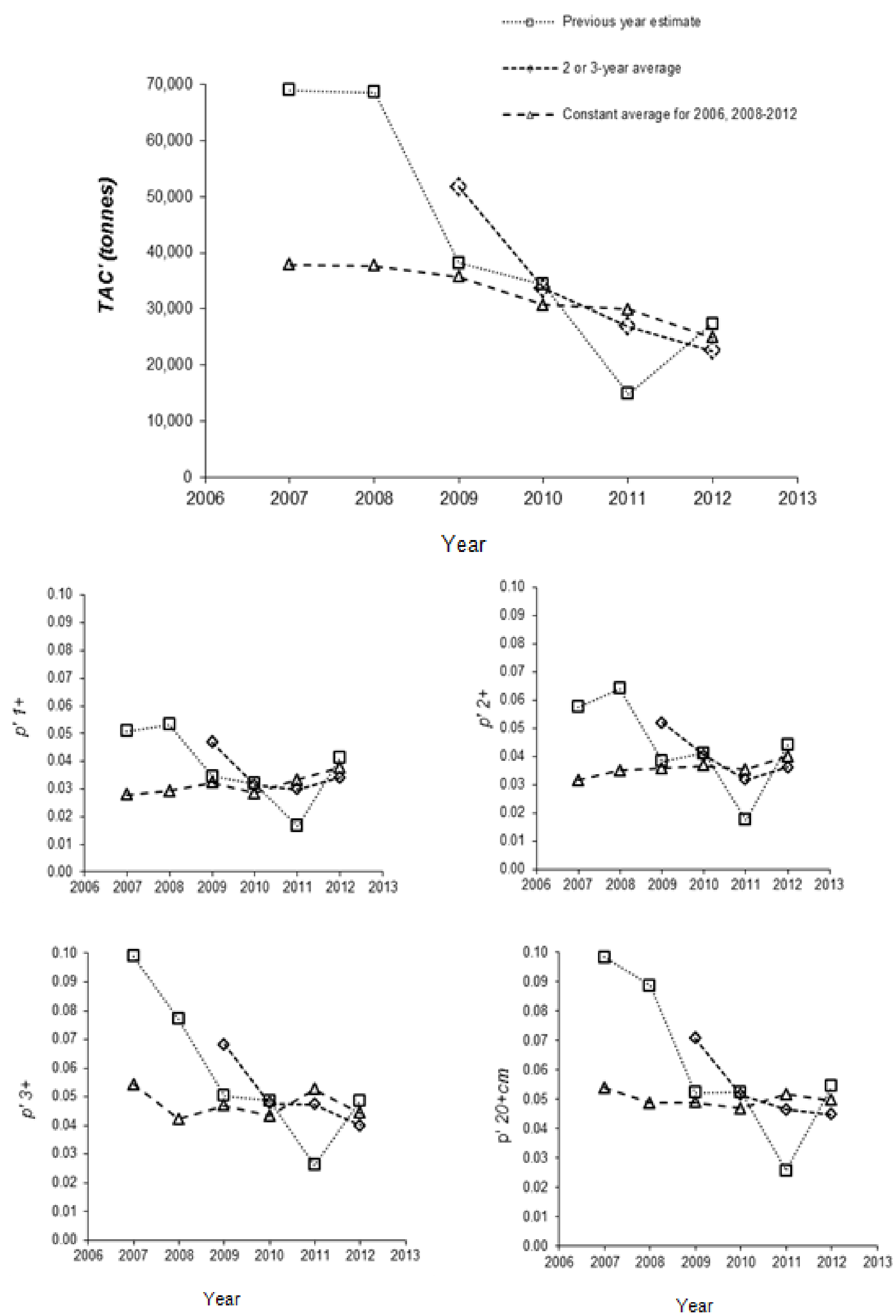


Figure 10. Type 1 harvest control rule output showing trends in the hypothetical total allowable catch (TAC') and population TAC ratio (p') by SS model population biomass estimate (age 1+, 2+, 3+ or 20+ cm fork length) from varying the age 1+ migration rate to represent a previous year, a 2 or 3-year average, or a 2006, 2008-2012 constant average. Only output derived from migration rates representing biomass for the WCVI core survey region with inlet extrapolation are shown.

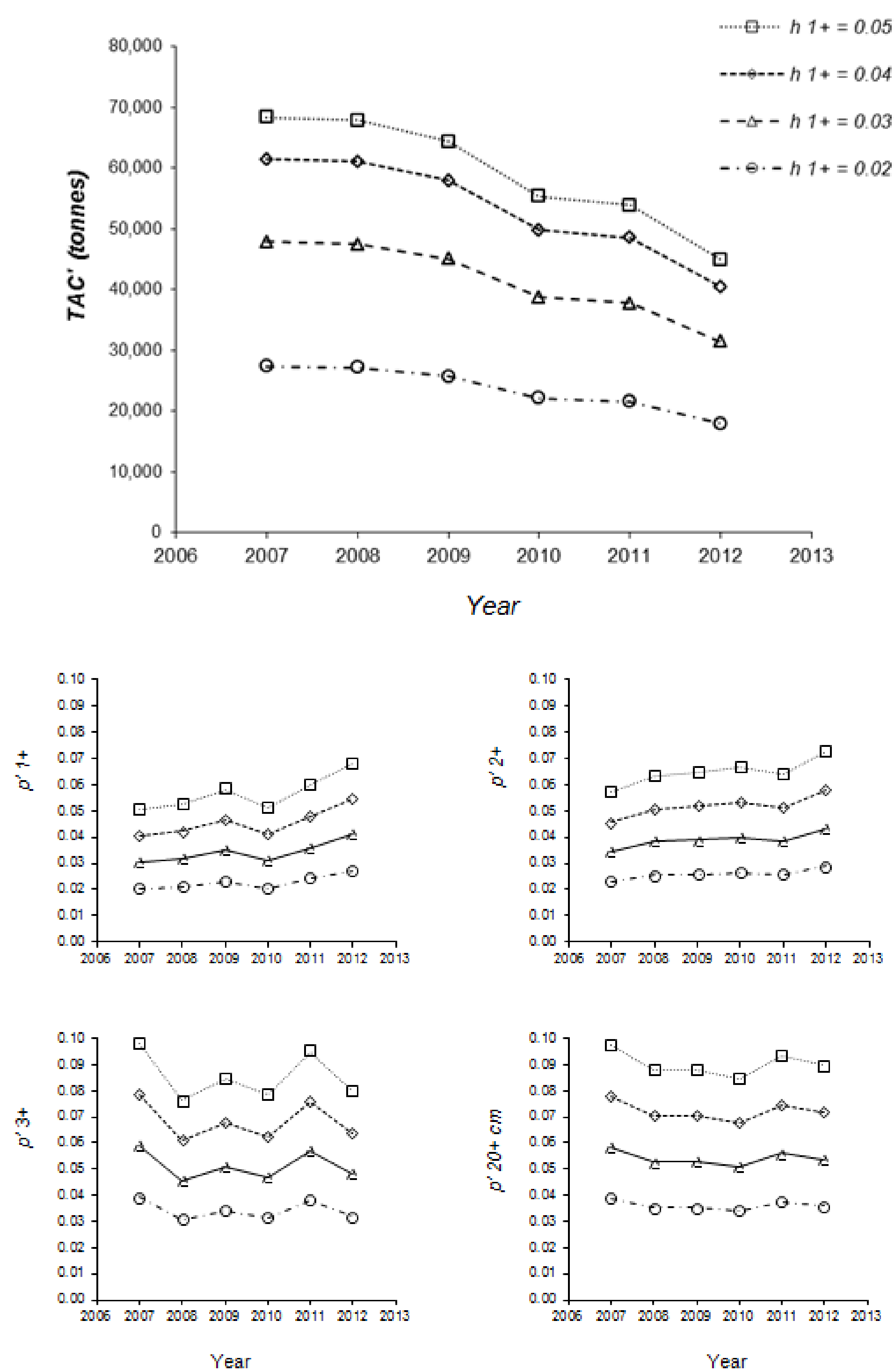


Figure 11. Type 2 harvest control rule output showing trends in the hypothetical total allowable catch (TAC') and population TAC ratio (p') by SS model population biomass estimate (age 1+, 2+, 3+ or 20+ cm fork length) from varying the harvest rate fraction (h_{1+})

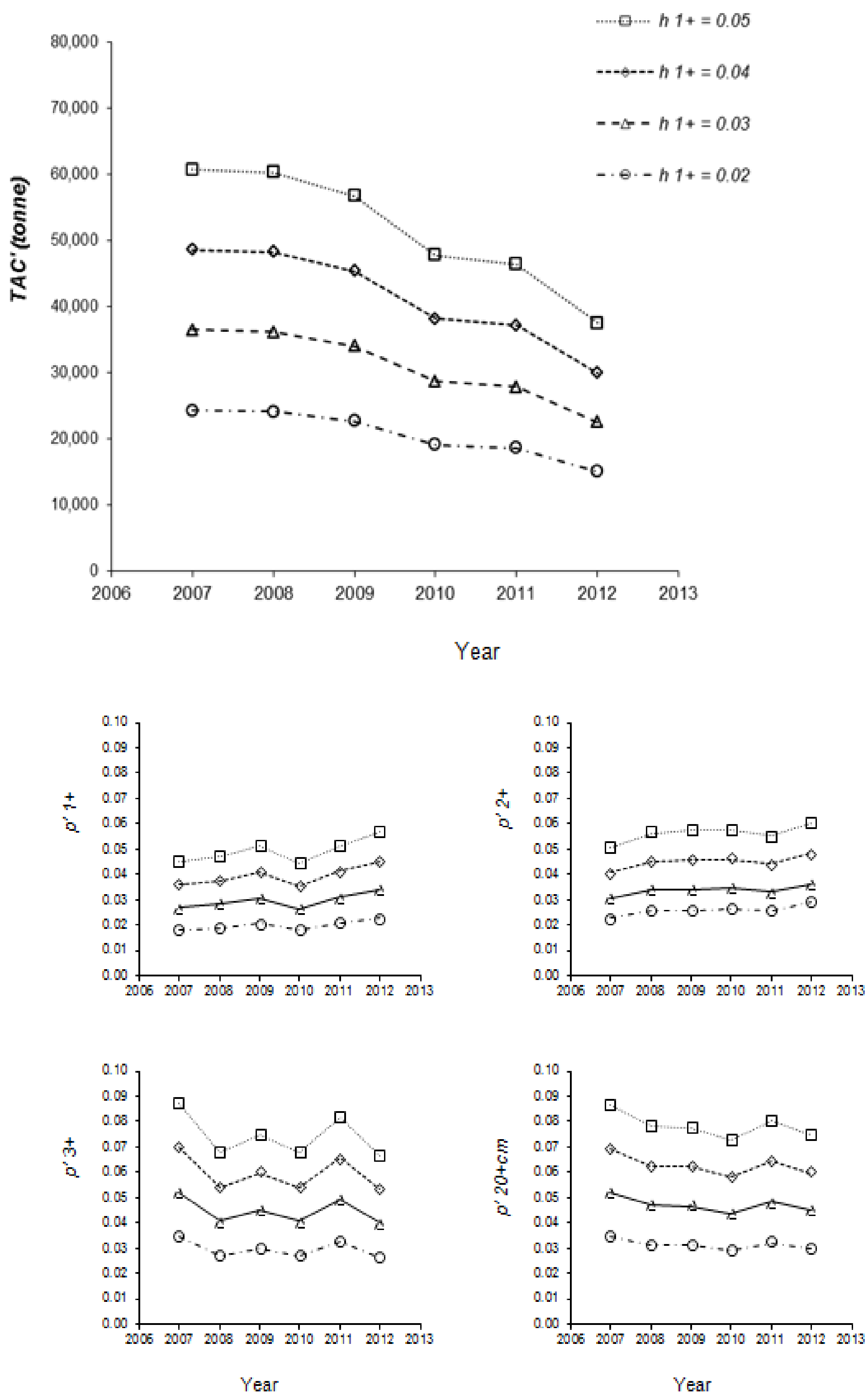


Figure 12. Type 3 harvest control rule output showing trends in the hypothetical total allowable catch (TAC') and population TAC ratio (p') by SS model population biomass estimate (age 1+, 2+, 3+ or 20+ cm fork length) from the inclusion of a cutoff parameter (150,000 t) and varying the harvest rate fraction (h_{1+}).

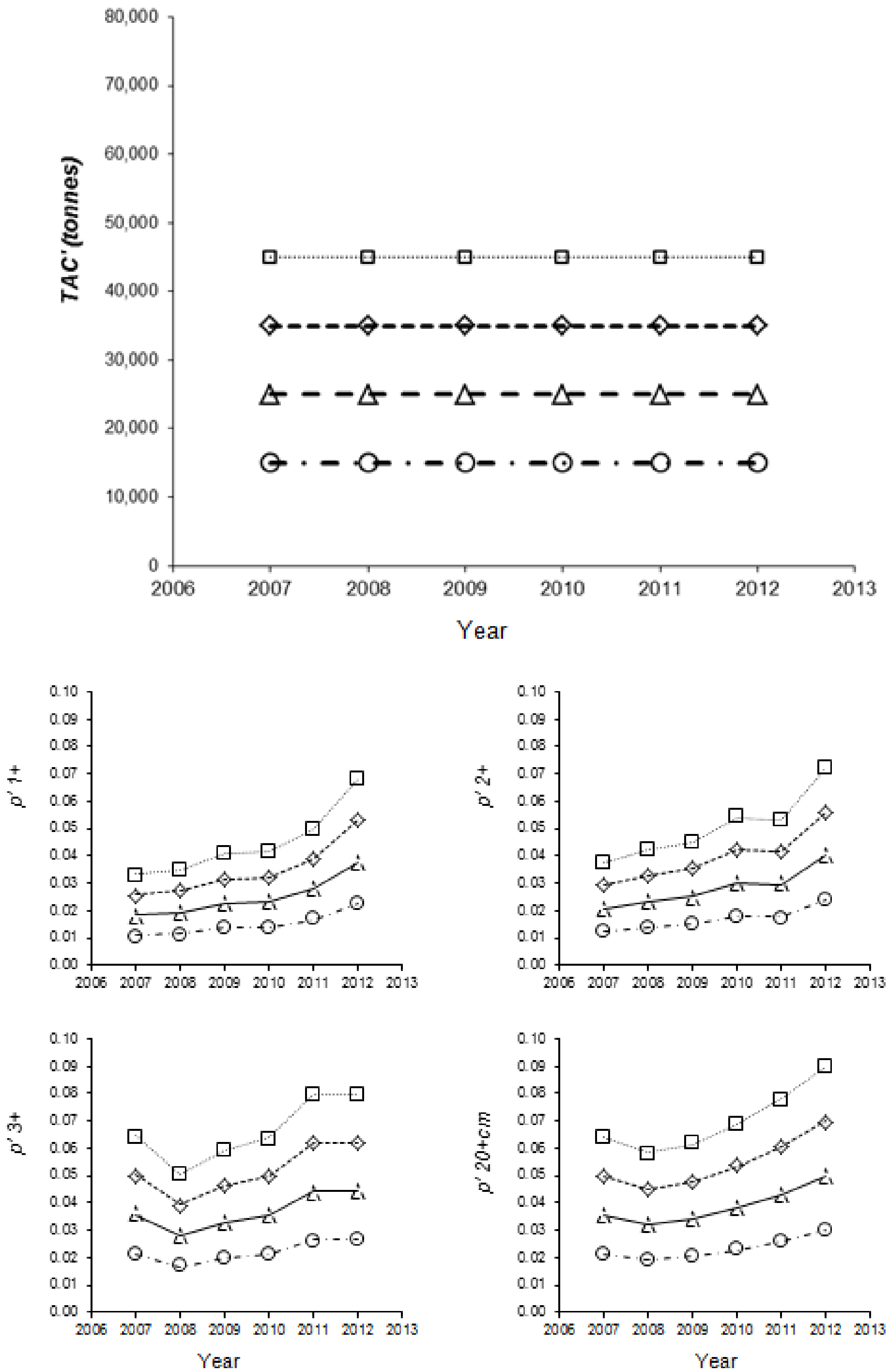


Figure 13. Type 4 harvest control rule output showing the hypothetical constant total allowable catch (TAC') from 15,000 to 45,000 tonnes and corresponding trends in population TAC ratio (p') by SS model population biomass estimate (age 1+, 2+, 3+ or 20+ cm fork length).

APPENDIX A. TRAWL SURVEY SARDINE DENSITIES AND CATCH LOCATIONS 2006, 2008-2012

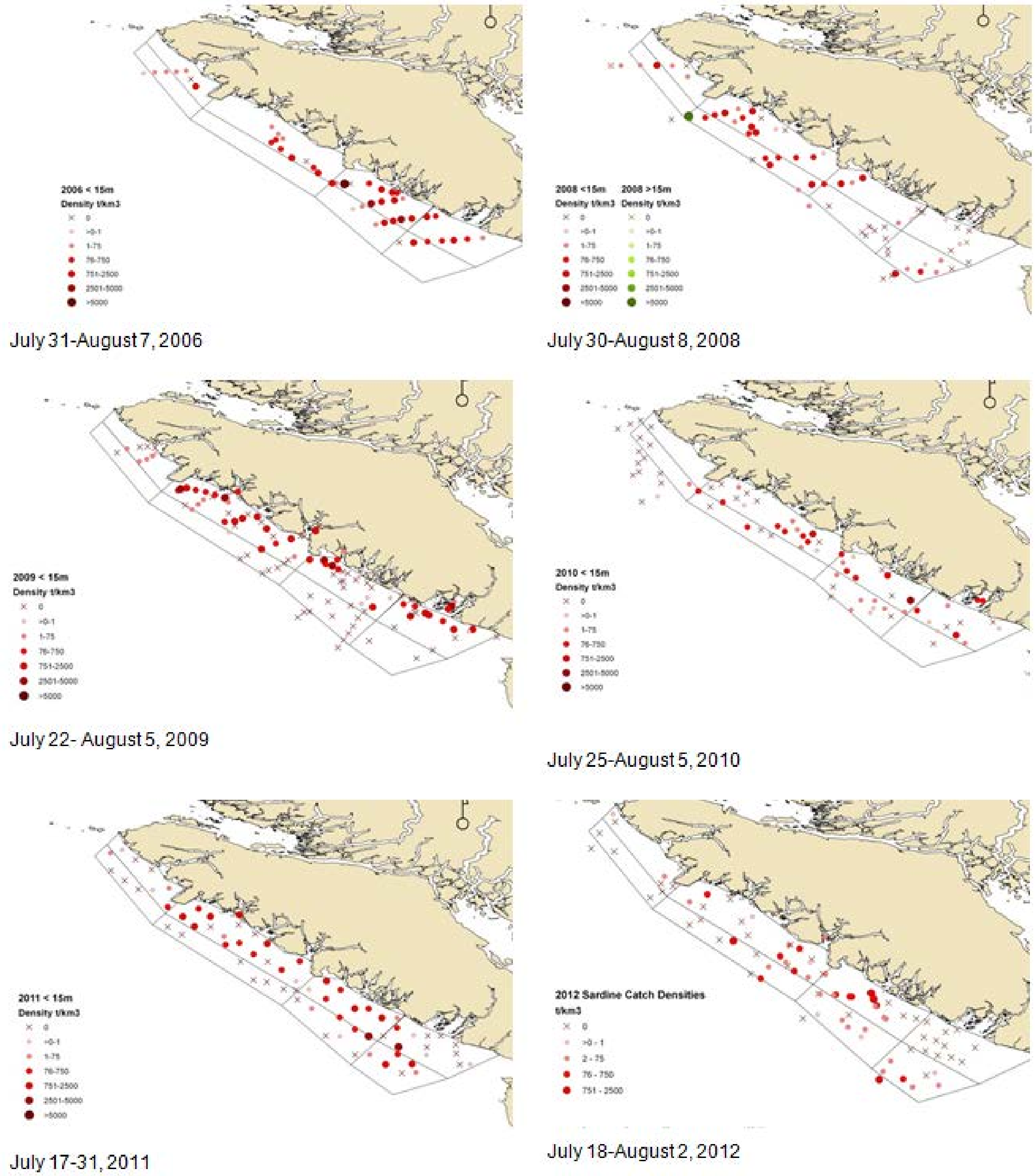


Figure A1. West coast of Vancouver Island trawl survey sampling locations, sampling dates and relative sardine catch densities (metric tonnes (t) per km3 of sea water).

APPENDIX B. DFO PACIFIC FISHERY MANAGEMENT AREAS AND 2012 MONTHLY SARDINE FISHERY LANDINGS

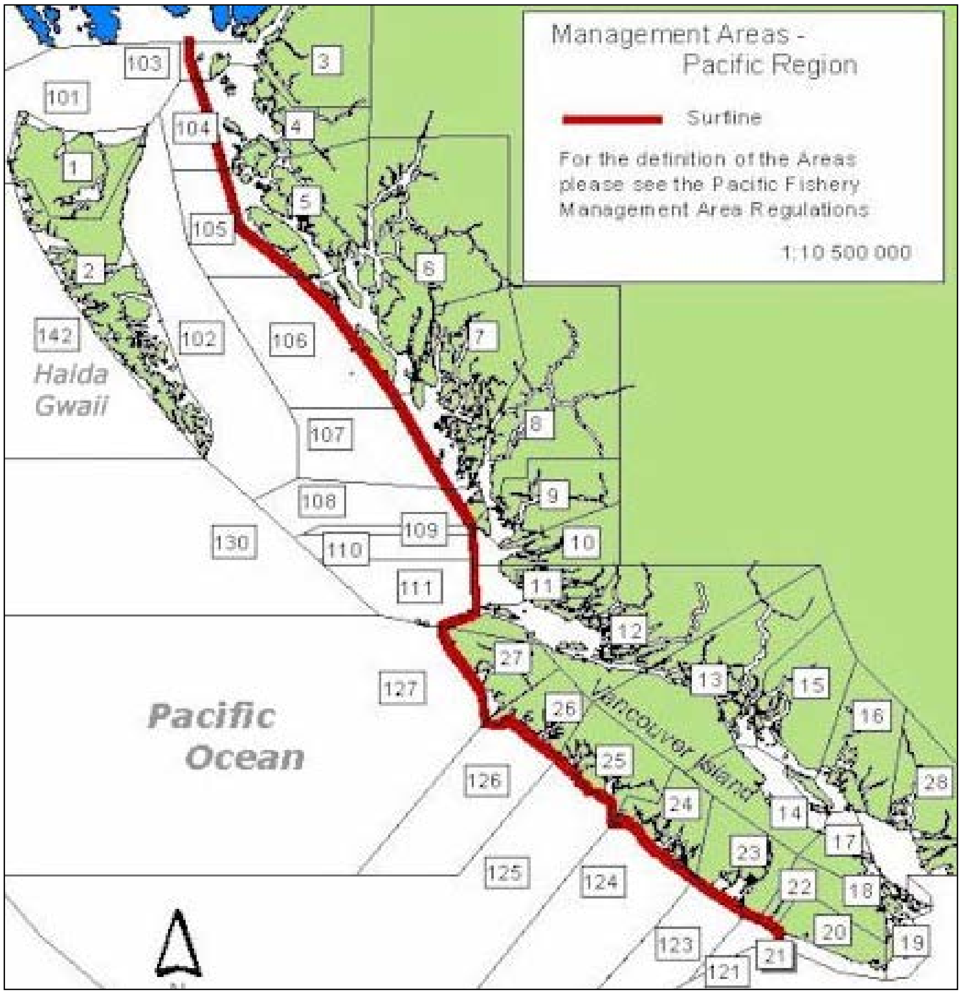


Figure B1. Fisheries and Oceans Canada Pacific Fishery Management Areas.

Table B1. Monthly estimates of 2012 BC sardine fishery landings (rounded to 50 tonnes).

Month	Landings (tonnes)
July	4,500
August	4,700
September	6,000
October	3,200
November	650
All	19,050

APPENDIX C. SARDINE FORK LENGTH AND STANDARD LENGTH RELATIONSHIPS

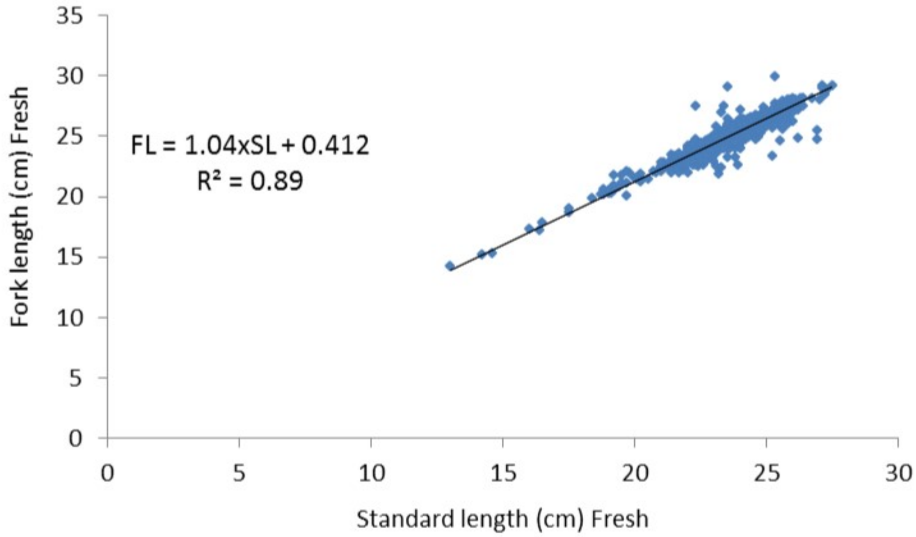


Figure C1. Linear regression for the relationship between sardine fork length and standard length from freshly sampled fish, N=1,688, from commercial seine (year 2001) and research trawl (year 2004) catches.

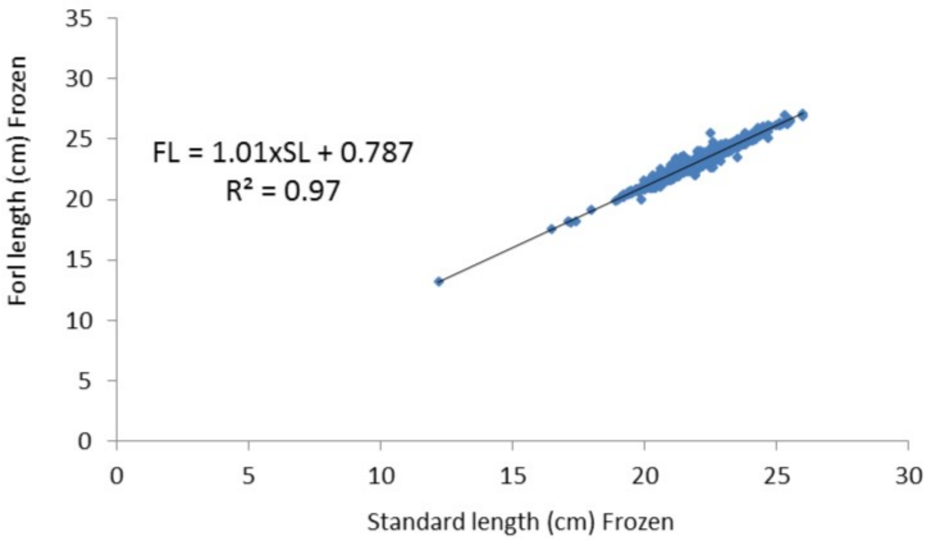


Figure C2. Linear regression for the relationship between sardine fork length and standard length from fish sampled after being frozen, N=11,829, from commercial seine catches (years 2007-2011).

APPENDIX D. SARDINE STANDARD LENGTH DISTRIBUTIONS FROM ACOUSTIC TRAWL SURVEYS

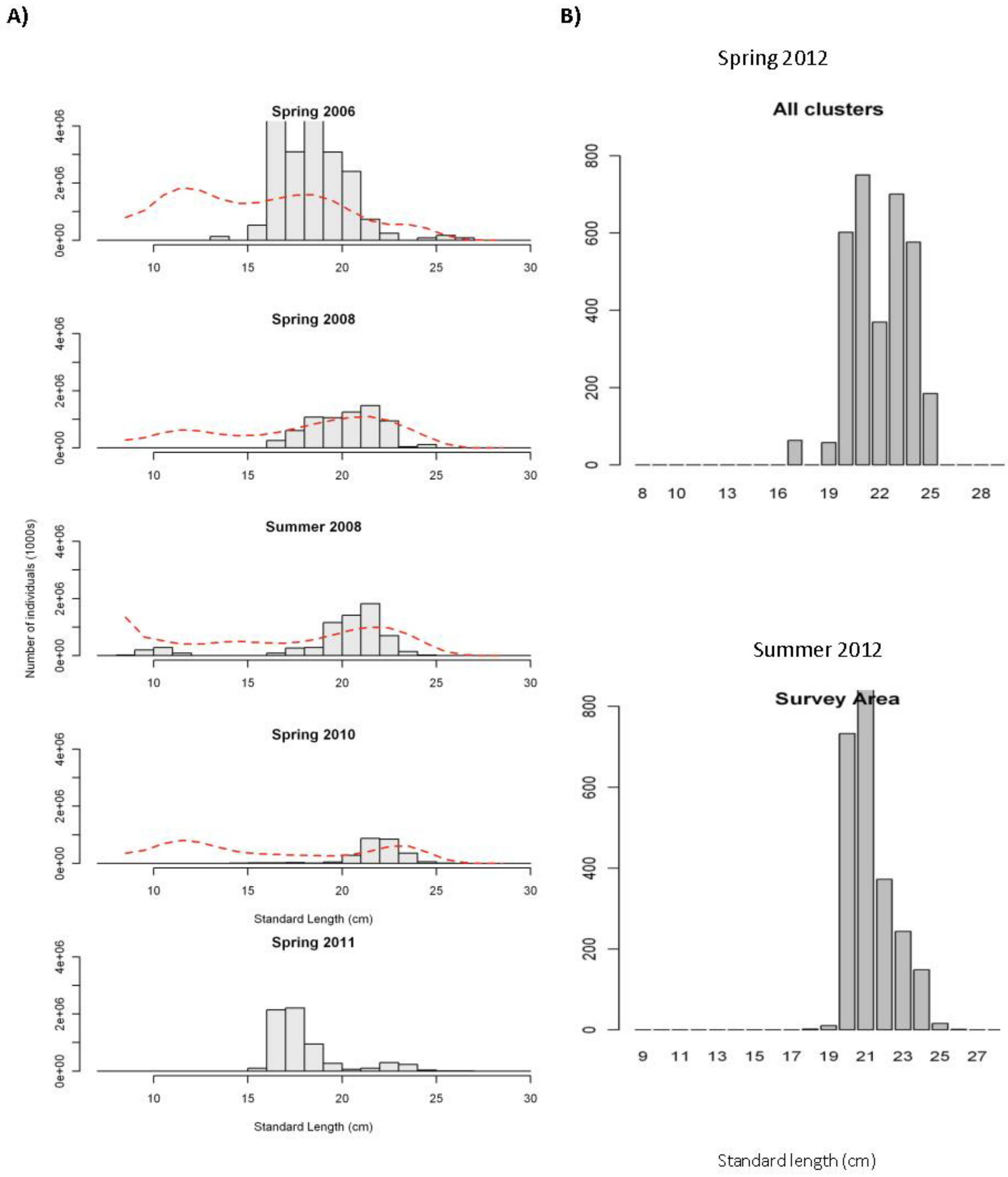


Figure D1. A- left side panel: Summary of standard length observations from acoustic-trawl surveys conducted in 2006, 2008, 2010 and 2011 (from Zwolinski et al 2011), red dotted lines are estimates from the 2011 Stock Synthesis model (Hill et al. 2011).B-right side panel: Summary of standard length observations from acoustic-trawl surveys conducted in the spring and summer of 2012 (Zwolinski et al 2012 in Hill et al 2012).

APPENDIX E. NOTATION

Table E1.Summary descriptions of index and parameter notation used in the report.

Notation	Description
Indices	
y	Year associated with a survey, a biomass estimate or a fishing season. • British Columbia fishing season is June 1 –February 9 of following calendar year (but most landings have occurred prior to December 31 of the same calendar year) • United States fishing season is January 1- December 31 of a calendar year
i	Region of British Columbia waters, representing either: • CSR: core survey region alone • CSR+IE: core survey region with inlet extrapolation
b	Population biomass estimate, representing one of: • 1+: Stock Synthesis assessment model age 1 and older • 2+: Stock Synthesis assessment model age 2 and older • 3+: Stock Synthesis assessment model age 3 and older • 20+ cm FL: Stock Synthesis assessment model 20 cm fork length and longer • ATsp: spring acoustic-trawl survey • ATsu: summer acoustic-trawl survey
c	Country or regional grouping of total allowable catch or landed catch, representing one of: • BC: Canada (British Columbia) • US: United States • BC+US: British Columbia and the United States combined • PNW: Pacific Northwest (British Columbia, Washington and Oregon combined)
Biomass and migration rate estimates and parameters	
$\bar{D}_{CSR,y}$	Average sardine trawl density estimate (tonnes/ km^3) for the west coast of Vancouver Island core survey region for year *y*.
$\bar{D}_{LL,y}$ $\bar{D}_{UL,y}$	Lower (*LL*) and upper (*UL*) limits of 90% confidence intervals for an average sardine trawl density estimate (tonnes/ km^3) for the west coast of Vancouver Island core survey region for year *y*.
V_i	Volumetric estimate of summer sardine habitat in British Columbia waters for region *i* • V_{CSR} = 502.2 km^3 • V_{CSR+IE} = 606.1 km^3
$I_{i,y}$	British Columbia summer sardine biomass estimate (tonnes) for region *i* derived from a trawl survey average density for year *y*.
$I_{LL,y}$ $I_{UL,y}$	Lower (*LL*) and upper (*UL*) limits of 90% confidence intervals for a sardine biomass estimate (tonnes) for the west coast of Vancouver Island core survey region for year *y*.
$B_{b,y}$	Type *b* sardine population biomass estimate for year *y* (tonnes)
$m_{i,b,y}$	Seasonal sardine migration rate estimate based on the ratio of a summer British Columbia biomass estimate for region *i* to a type *b* population biomass estimate for year *y*.
$\bar{m}_{i,b,y}$	Two or three season average sardine migration rate estimate based on the ratio of summer British Columbia biomass estimates for region *i* to type *b* population biomass estimates for a series of years ending in *y*.
$\hat{m}_{i,b,2006\text{-}2012}$	Six season average sardine migration rate estimate based on the ratio of summer British Columbia biomass estimates for region *i* to type *b* population biomass estimates for years 2006, 2008-2012.

Notation	Description
Distribution and harvest rate fractions in harvest control rules	
d_{US}	Distribution factor for United States sardine fishery harvest control rule (constant = 0.87)
h_{US}	Harvest fraction for United States sardine fishery harvest control rule (0.15 during 1998-2012)
h_{BC}	Harvest rate fraction for British Columbia sardine fishery harvest control rule (0.15 during 2002-2012)
h_{1+}	Harvest rate fraction for Type 2 and 3 alternative British Columbia sardine fishery harvest control rules, values range from 0.02 to 0.05 with increments of 0.005.
Fishery exploitation	
$TAC'_{US,y}$	Potential United States sardine fishery total allowable catch (tonnes) for a fishing season in year *y* resulting from a harvest control rule calculation.
$TAC'_{BC,y}$	Potential British Columbia sardine fishery total allowable catch (tonnes) for a fishing season in year *y* resulting from a harvest control rule calculation.
$TAC_{c,y}$	Total allowable catch (tonnes) for country *c* for a fishing season in year *y*.
TAC'_{y}	Hypothetical British Columbia sardine fishery total allowable catch (tonnes) for year y, resulting from one of the four types of demonstrated harvest control rules.
$C_{c,y}$	Reported landed catch (tonnes) for region *c* for a fishing season in year *y*.
$p_{i,y}$	Ratio of a British Columbia sardine fishery total allowable catch to an estimate of British Columbia summer biomass for region *i* for year *y*.
$p_{c,b,y}$	Ratio of a total allowable catch for country *c* to a type *b* population biomass estimate for year *y*.
$p'_{b,y}$	Ratio of a hypothetical British Columbia sardine fishery total allowable catch amount to a type *b* Stock Synthesis population biomass estimate for year y, resulting from one of the four types of demonstrated harvest control rules.
$u_{,i,y}$	British Columbia sardine fishery exploitation rate estimate based on the ratio of reported catch to an estimate of British Columbia summer biomass for region *i* for year *y*.
$u_{c,b,y}$	Fishery exploitation rate by country or region based on the ratio of the reported catch for region *c* to a type *b* population biomass estimate for year *y*.

APPENDIX F. ADDITIONAL TYPE 2 HARVEST CONTROL RULE OUTPUT

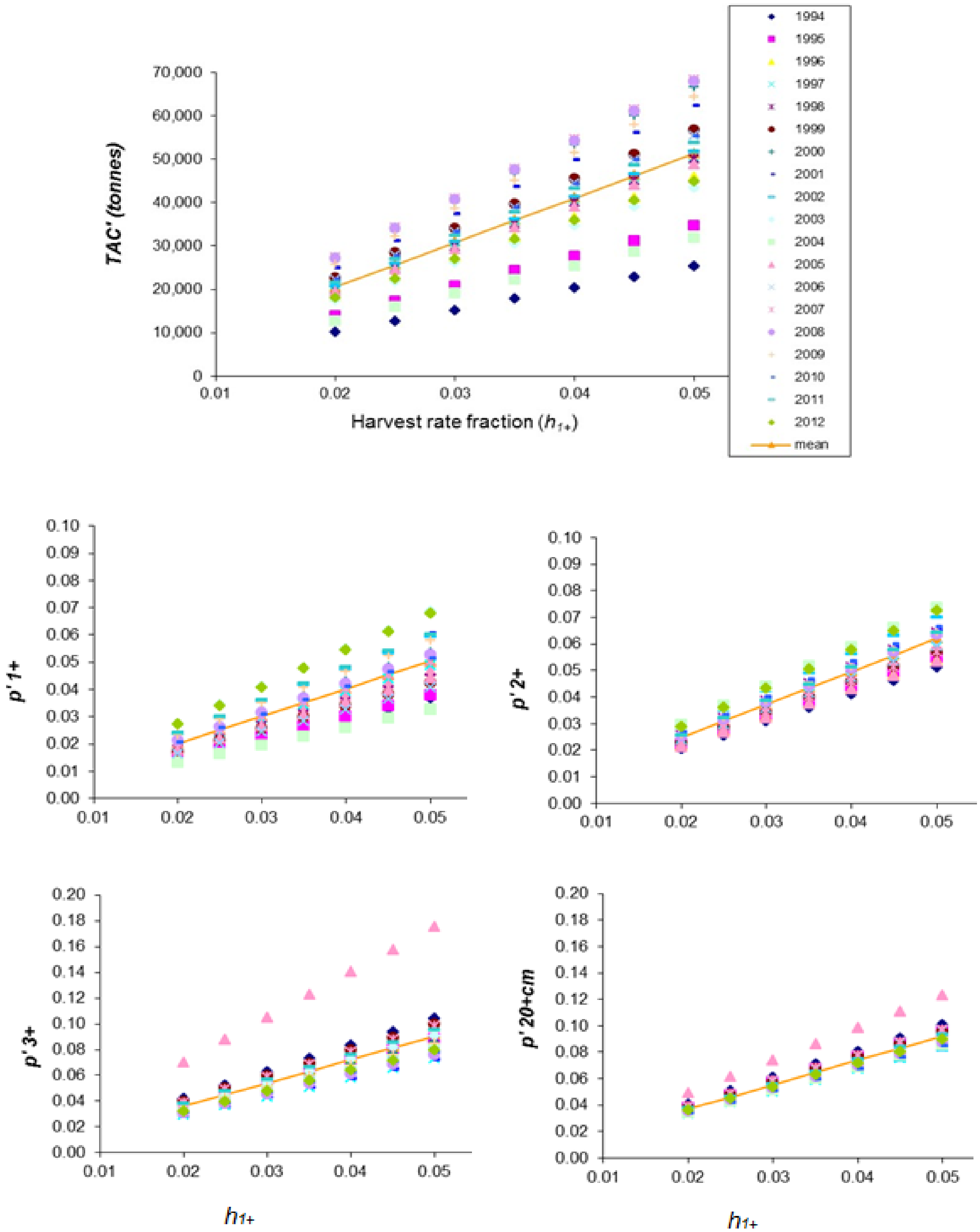


Figure F1. Hypothetical total allowable catch amounts (TAC') and ratios of TAC' to population biomass estimates (p') for 1994 to 2012 from varying the harvest rate fraction h_{1+}. Not all scales are equal.

Table F1. Type 2 HCR summary statistics for 1994 to 2012 hypothetical TAC' and p' output.

h_{1+}	0.020	0.025	0.030	0.035	0.040	0.045	0.050
TAC'							
Mean	20,542	25,678	30,814	35,949	41,085	46,220	51,356
Median	20,655	25,819	30,983	36,147	41,310	46,474	51,638
Min	10,146	12,683	15,220	17,756	20,293	22,829	25,366
Max	27,320	34,150	40,979	47,809	54,639	61,469	68,299
SD	4,846	6,057	7,269	8,480	9,692	10,903	12,115
CV	0.236	0.236	0.236	0.236	0.236	0.236	0.236
p'_{1+}							
Mean	0.020	0.025	0.030	0.035	0.040	0.045	0.050
Median	0.020	0.025	0.030	0.035	0.040	0.045	0.050
Min	0.013	0.016	0.019	0.023	0.026	0.029	0.032
Max	0.027	0.034	0.041	0.048	0.055	0.062	0.068
SD	0.004	0.005	0.006	0.007	0.008	0.009	0.010
CV	0.205	0.205	0.205	0.205	0.205	0.205	0.205
p'_{2+}							
Mean	0.025	0.031	0.037	0.043	0.050	0.056	0.062
Median	0.025	0.032	0.038	0.044	0.051	0.057	0.063
Min	0.021	0.026	0.031	0.036	0.041	0.046	0.051
Max	0.029	0.037	0.044	0.051	0.059	0.066	0.073
SD	0.003	0.003	0.004	0.005	0.005	0.006	0.007
CV	0.110	0.110	0.110	0.110	0.110	0.110	0.110
p'_{3+}							
Mean	0.036	0.045	0.054	0.063	0.072	0.081	0.090
Median	0.035	0.043	0.052	0.060	0.069	0.078	0.086
Min	0.029	0.036	0.043	0.050	0.058	0.065	0.072
Max	0.070	0.088	0.105	0.123	0.140	0.158	0.175
SD	0.009	0.011	0.013	0.016	0.018	0.020	0.022
CV	0.249	0.249	0.249	0.249	0.249	0.249	0.249
p'_{20+cm}							
Mean	0.037	0.046	0.055	0.065	0.074	0.083	0.092
Median	0.036	0.045	0.054	0.064	0.073	0.082	0.091
Min	0.033	0.041	0.049	0.057	0.066	0.074	0.082
Max	0.049	0.061	0.074	0.086	0.098	0.111	0.123
SD	0.004	0.005	0.005	0.006	0.007	0.008	0.009
CV	0.099	0.099	0.099	0.099	0.099	0.099	0.099

APPENDIX G. ADDITIONAL TYPE 3 HARVEST CONTROL RULE OUTPUT

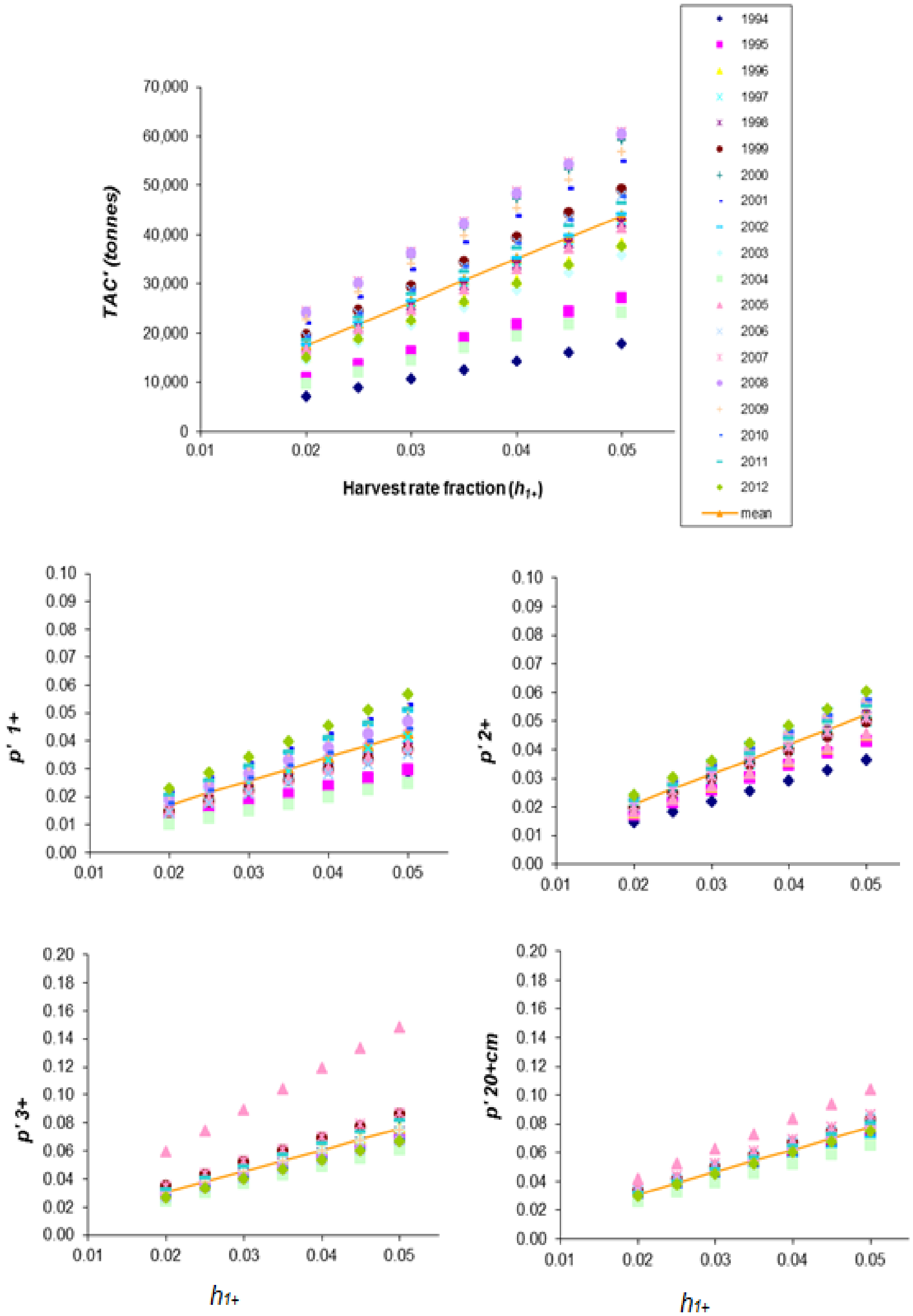


Figure G1. Hypothetical total allowable catch amounts (TAC') and ratios of TAC' to population biomass estimates (p') for 1994 to 2012 from varying the harvest rate fraction h_{1+}. Not all scales are equal.

Table G1. Type 3 HCR summary statistics for 1994 to 2012 hypothetical TAC' and p' output.

h_{1+}	0.020	0.025	0.030	0.035	0.040	0.045	0.050
Cutoff = 150,000 tonnes							
TAC'							
Mean	17,539	21,924	26,309	30,693	35,078	39,463	43,848
Median	17,647	22,059	26,471	30,883	35,294	39,706	44,118
Min	7,143	8,929	10,714	12,500	14,286	16,072	17,857
Max	24,316	30,395	36,475	42,554	48,633	54,712	60,791
SD	4,843	6,053	7,264	8,474	9,685	10,896	12,106
CV	0.276	0.276	0.276	0.276	0.276	0.276	0.276
p'_{1+}							
Mean	0.017	0.021	0.026	0.030	0.034	0.038	0.043
Median	0.018	0.022	0.027	0.031	0.035	0.040	0.044
Min	0.010	0.012	0.015	0.017	0.020	0.022	0.025
Max	0.023	0.028	0.034	0.040	0.045	0.051	0.057
SD	0.004	0.005	0.006	0.007	0.008	0.009	0.010
CV	0.228	0.228	0.228	0.228	0.228	0.228	0.228
p'_{2+}							
Mean	0.021	0.026	0.031	0.037	0.042	0.047	0.052
Median	0.022	0.027	0.033	0.038	0.044	0.049	0.055
Min	0.014	0.018	0.022	0.025	0.029	0.033	0.036
Max	0.024	0.030	0.036	0.042	0.048	0.054	0.060
SD	0.003	0.003	0.004	0.005	0.005	0.006	0.007
CV	0.124	0.124	0.124	0.124	0.124	0.124	0.124
p'_{3+}							
Mean	0.030	0.038	0.046	0.053	0.061	0.068	0.076
Median	0.029	0.037	0.044	0.051	0.059	0.066	0.073
Min	0.024	0.031	0.037	0.043	0.049	0.055	0.061
Max	0.059	0.074	0.089	0.104	0.119	0.133	0.148
SD	0.008	0.010	0.011	0.013	0.015	0.017	0.019
CV	0.250	0.250	0.250	0.250	0.250	0.250	0.250
p'_{20+cm}							
Mean	0.031	0.039	0.047	0.054	0.062	0.070	0.078
Median	0.030	0.038	0.046	0.053	0.061	0.068	0.076
Min	0.026	0.033	0.039	0.046	0.052	0.059	0.065
Max	0.042	0.052	0.062	0.073	0.083	0.094	0.104
SD	0.003	0.004	0.005	0.006	0.007	0.007	0.008
CV	0.106	0.106	0.106	0.106	0.106	0.106	0.106

APPENDIX H. ADDITIONAL TYPE 4 HARVEST CONTROL RULE OUTPUT

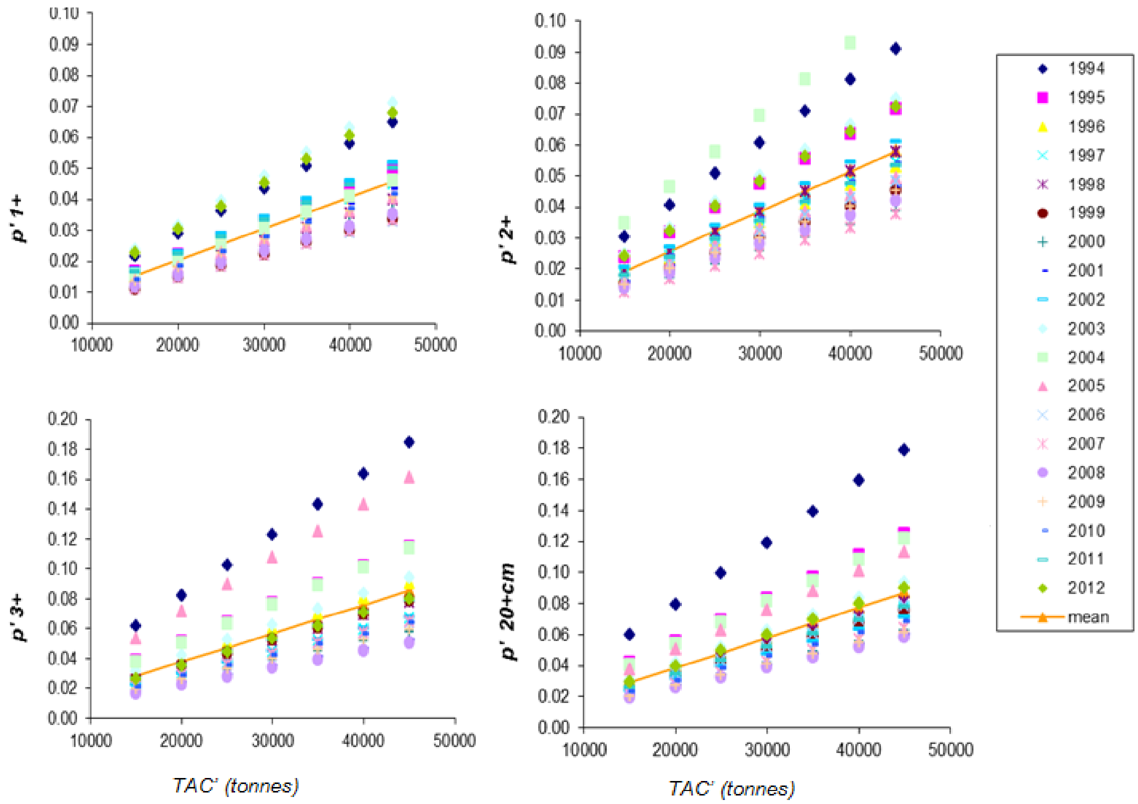


Figure H1. Hypothetical total allowable catch amounts (TAC') and ratios of TAC' to population biomass estimates (p') for 1994 to 2012 from varying constant total allowable catch amounts from 15,000 to 45,000 tonnes. Not all scales are equal.

Table H1. Type 4 HCR summary statistics for 1994 to 2012 hypothetical TAC' and p' output.

Constant *TAC'*		**15,000**	**20,000**	**25,000**	**30,000**	**35,000**	**40,000**	**45,000**
p'_{1+}								
	Mean	0.015	0.020	0.025	0.031	0.036	0.041	0.046
	Median	0.015	0.019	0.024	0.029	0.034	0.039	0.044
	Min	0.011	0.015	0.018	0.022	0.026	0.029	0.033
	Max	0.024	0.032	0.039	0.047	0.055	0.063	0.071
	SD	0.004	0.005	0.006	0.008	0.009	0.010	0.011
	CV	0.250	0.250	0.250	0.250	0.250	0.250	0.250
p'_{2+}								
	Mean	0.019	0.026	0.032	0.039	0.045	0.052	0.058
	Median	0.018	0.024	0.030	0.036	0.042	0.048	0.053
	Min	0.013	0.017	0.021	0.025	0.029	0.033	0.038
	Max	0.035	0.046	0.058	0.070	0.081	0.093	0.104
	SD	0.006	0.008	0.010	0.012	0.014	0.016	0.018
	CV	0.306	0.306	0.306	0.306	0.306	0.306	0.306
$p'3_{+}$								
	Mean	0.028	0.038	0.047	0.057	0.066	0.076	0.085
	Median	0.026	0.035	0.043	0.052	0.061	0.069	0.078
	Min	0.017	0.022	0.028	0.034	0.039	0.045	0.051
	Max	0.061	0.082	0.102	0.123	0.143	0.164	0.184
	SD	0.012	0.016	0.020	0.024	0.028	0.032	0.036
	CV	0.421	0.421	0.421	0.421	0.421	0.421	0.421
p'_{20+cm}								
	Mean	0.029	0.039	0.048	0.058	0.068	0.077	0.087
	Median	0.026	0.035	0.043	0.052	0.061	0.069	0.078
	Min	0.010	0.013	0.017	0.020	0.023	0.027	0.030
	Max	0.019	0.026	0.032	0.039	0.045	0.052	0.058
	SD	0.010	0.013	0.017	0.020	0.023	0.027	0.030
	CV	0.345	0.345	0.345	0.345	0.345	0.345	0.345

APPENDIX I. TYPE 3 HARVEST CONTROL RULE THEORETICAL TREND BETWEEN EFFECTIVE HARVEST RATE AND POPULATION BIOMASS

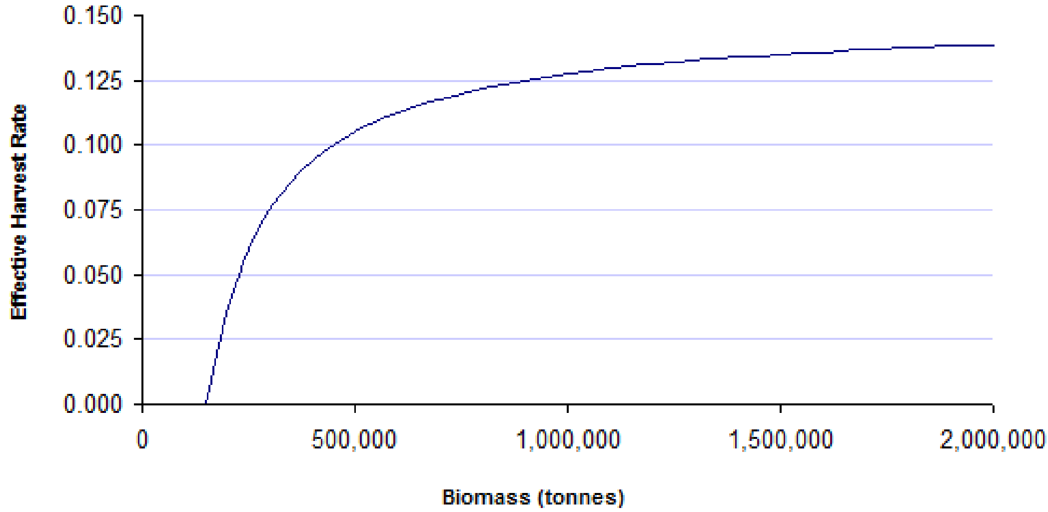


Figure I1. Theoretical relationship between effective harvest rate and estimated population biomass from a type 3 harvest control rule, which applies a harvest rate of 0.15 to the difference between a population biomass estimate and an escapement buffer (cutoff) of 150,000 tonnes. This relationship assumes the population biomass to be constant for setting potential total allowable catch and estimating effective harvest rate:

Potential total allowable catch (tonnes) = h x (Biomass – 150,000)

Where h = 0.15

Effective harvest rate = Potential total allowable catch / Biomass

APPENDIX J. SUMMER 2012 MEAN DAILY CHLOROPHYLL SATELLITE IMAGES

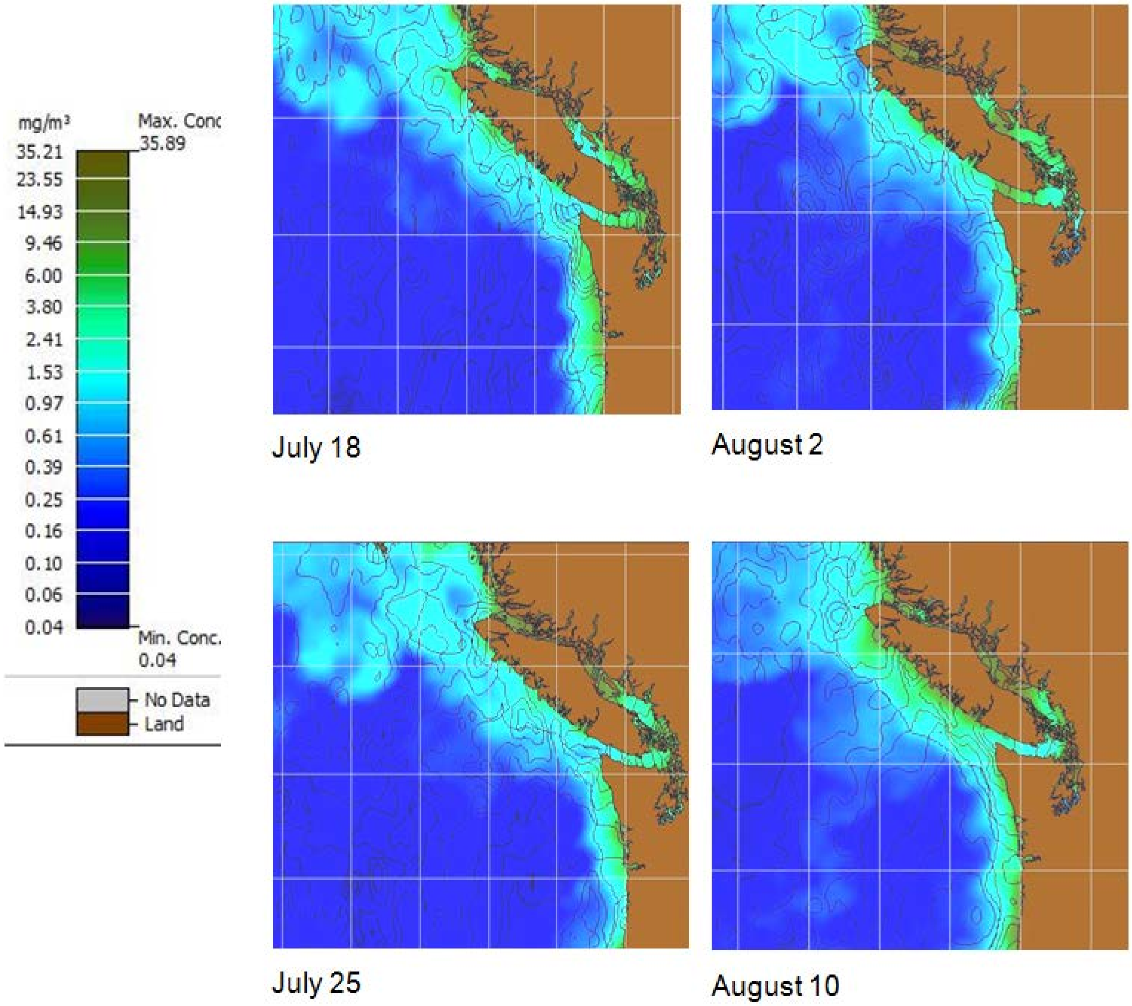


Figure J1. Mean daily chlorophyll satellite images for waters surrounding Vancouver Island from July 18- August 10, 2012. Dates depict conditions at the beginning, middle and end of the 2012 WCVI trawl survey (conducted July 18 to August 2).Source: GeoEye Inc. 2013

APPENDIX K. SUMMER 2012 MEAN WEEKLY SEA SURFACE TEMPERATURE SATELLITE IMAGES

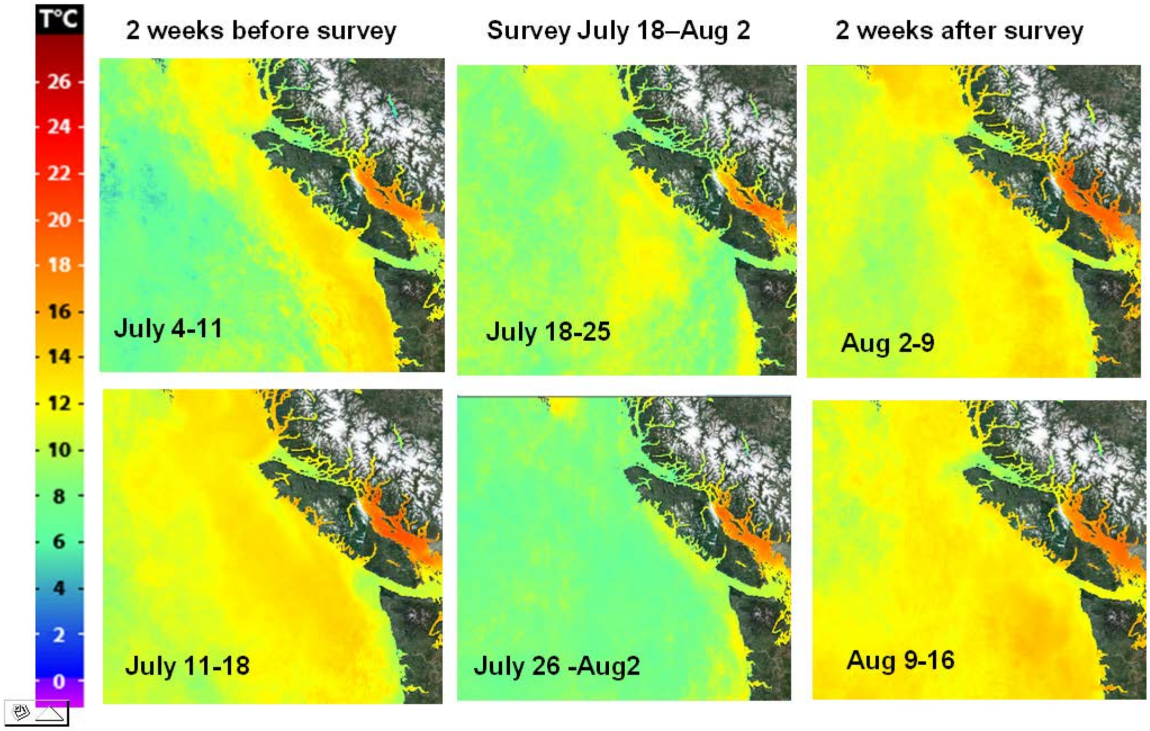


Figure K1. Mean weekly sea surface temperature satellite images for waters surrounding Vancouver Island from July 4- August 16, 2012. Dates depict conditions at the beginning, middle and end of the 2012 WCVI trawl survey (conducted July 18 to August 2).Source: St. Lawrence Global Observatory 2012, http://slgo.ca/en/remotesensing/data.html.