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Initial investigations on potential impacts of reductions in spawn survey and bio-sampling program effort on herring stock assessments and management advice

Études initiales sur les impacts possibles de la réduction des relevés de la ponte et de l'échantillonnage biologique sur l'évaluation des stocks et les conseils relatifs à la gestion de la pêche du hareng

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Abstract

B.C. herring stock assessments are supported by a rich database that encompasses surveys of spawning stock abundance and biological data that span over a 56-year history. While responsibility for data collection has changed over time, recent changes may affect the ability to maintain herring data acquisition programs at previous levels. This has raised concern about the potential impact of degradation in the herring data collection systems on stock assessments and management advice.

This paper uses simulation methods to investigate how different levels of sampling effort in the biological sampling spawn surveys program might impact herring stock assessments. Specifically, the question of how different the 2006 stock assessments would have been if data collection programs had changed some time in the recent past is addressed.

Results of the simulations allow some general conclusions about the potential impacts of reductions in bio-sampling and spawn survey program effort on herring stock assessments and management advice. Program changes that effect only the bio-sampling data would likely have relatively minor impact on estimates of spawning stock biomass but would have greater effects on stock forecasts and estimates of potential yields, though without obvious bias. Reduced effort for spawn survey programs introduces a negative bias to the spawn survey data, which translates to comparable levels of negative bias in estimates of spawning abundance. The use of a model that synthesizes both the spawn and age-composition data allows some compensation in stock forecasts, particularly when there are only a few years of biased spawn data. For simulations that included both the bio-sampling and spawn survey data quality effects, stock forecast estimates were more strongly affected and had larger negative biases than when only reduced spawn survey data quality was simulated.

Results of the simulations are primarily intended for illustrative purposes and do not quantify the direct effect of various levels of sampling effort on stock assessments and management advice. Evaluation of the trade-offs between sampling effort (and associated costs) and stock assessment precision and accuracy is beyond the scope of this analysis. Analyses to pursue those objectives would require development of a fully prescribed operating model.

Résumé

L'évaluation des stocks de hareng de la Colombie-Britannique s'appuie sur une riche base de données englobant les relevés d'abondance du stock de reproducteurs échelonnés sur 56 ans. Bien qu'au fil du temps, la collecte de ces données ait relevé de différents secteurs de compétence, certains changements récents pourraient nuire à notre capacité de maintenir les programmes d'acquisition de données aux niveaux de qualité antérieurs. En conséquence, certaines préoccupations ont été soulevées quand aux effets possible d'une dégradation des systèmes de collecte de données sur l'évaluation des stocks et les conseils à propos de la gestion de la pêche du hareng.

La présente étude fait appel à la simulation pour mesurer l'effet de différents degrés d'effort dans le cadre des programmes de relevés de ponte et d'échantillonnage biologique sur l'évaluation des stocks de hareng. De manière plus précise, le but était de découvrir dans quelle mesure les évaluations des stocks de 2006 auraient varié dans l'éventualité où les programmes de collecte de données auraient subi de récents changements.

Les résultats obtenus par simulation permettent d'en arriver à certaines conclusions d'ordre général quant aux répercussions possibles de coupures dans les programmes de relevés de la ponte et d'échantillonnage biologique sur l'évaluation des stocks de hareng et la formulation d'avis sur la gestion de la pêche. Des changements apportés au programme qui ne toucheraient que l'échantillonnage biologique n'auraient que très peu de répercussions sur les évaluations de la biomasse génitrice. Leur impact serait cependant plus marqué sur les prévisions des stocks et l'évaluation des rendements potentiels sans toutefois de biais évidents. Des coupures dans l'effort de relevés de la ponte introduiraient un biais négatif dans les données en résultant, ce qui se traduirait par un biais négatif d'un degré comparable dans les évaluations d'abondance des reproducteurs. L'emploi d'un modèle apte à reproduire synthétiquement à la fois les données sur la ponte et sur la composition du stock selon l'âge permettrait de compenser l'erreur dans une certaine mesure dans la prévision des stocks, surtout si les relevés de ponte biaisés ne concernent que quelques années seulement. Pour ce qui est des simulations révélant l'impact des coupures sur la qualité des données, aussi bien de l'échantillonnage biologique que des relevés de pontes, elles montrent que les prévisions des stocks sont plus sévèrement touchées et comportent des biais négatifs plus importants que dans le cas des simulations limitées aux relevés de ponte.

Les résultats des simulations étaient essentiellement voués à illustrer plutôt qu'à quantifier l'effet direct de différents degrés d'effort d'échantillonnage sur l'évaluation des stocks et la formulation des avis sur la gestion des pêches. L'évaluation du compromis à faire entre la diminution des échantillonnages (et des coûts afférents) et l'exactitude et la précision de l'évaluation des stocks de harengs dépasse le cadre de la présente analyse. Toute analyse menée dans cette optique exigerait l'élaboration d'un modèle entièrement dédié.

1 Introduction

B.C. herring stock assessments are supported by a rich database that encompasses surveys of spawning stock abundance and biological data that span over a 56-year history. While there have been some changes to the data collection methods, these have been minor relative to the overall consistency of the information in the data systems.

Annual spawn surveys, originally conducted using surface survey techniques were replaced by diver survey methods in the late 1980s. However, the basic information collected, the areas of spawning events and average egg density remains the same. Biological information, including age-composition and size-at-age data, have been regularly collected from commercial fisheries and since the early 1970s these have been augmented with samples from charter fishery programs.

Responsibility for the conduct and funding of the assessment-related data collection programs has changed over time. A recent legal decision prevents DFO and industry from supporting assessment-related data collection programs through the sale of fish, and thus the ability to maintain herring data acquisition programs at previous levels is in question. As a result concern has been raised about the potential impact of degradation in the herring data collection systems on stock assessments and management advice.

The objective of the work described in this document is to investigate how different levels of sampling effort in the biological sampling program and the spawn survey program might impact herring stock assessments and how this might translate through to management advice. A comprehensive examination of this question would involve development of operating models for simulating stock dynamics and data collection programs. We adopt a simpler and pragmatic approach to addressing the issue. That is, we use the existing data and ask the question, how different would the 2006 stock assessments have been if data collection programs had changed some time in the recent past. This work is perforce illustrative, because we do not know how data collection programs will change if resources to conduct them are reduced.

2 Methods

We adopt a simple approach to investigate the effect of alternative levels of sampling effort for the spawn survey program and the biological sampling program. First, we assume that the stock reconstructions resulting from the 2006 herring stock assessments reflect the "true" stocks and the data sets used for these analyses result from *high* levels of effort in the data collection programs. This does not imply perfect data, rather that the *high* level is consistent with previous sampling effort. We then define how *moderate* or *low* levels of sampling effort could modify the data observations. A sub-set of observations from the original data sets is replaced with alternative data to generate replicate alternative data sets. Data observations are replaced for a specified number of years at the terminal end of the data sets. Thus we investigate the effect of a change to the data collection programs at some time in the recent past.

Using the 2006 stock assessment data sets as templates, the data for all years following a specified *transition year* are replaced to generate an alternative assessment data set. The stock assessment model is rerun and alternative stock reconstructions and stock projections estimated and compared with those from the original (*base case*) assessment. For both the original and alternative assessments, only MPD (Mode of Posterior Distribution) estimates are obtained.

Details of the assessment model used for the 2006 herring stock assessments and the analyses presented here, HCAM version R20, is described in Schweigert and Haist (2007) and only details pertinent to the current analysis are described here. The assessment model is a catch-age model that incorporates spawn survey data as an index of spawning abundance. For the period up to 1988, the spawn survey data is treated as a relative index and a spawn index-true spawn proportionality constant (q) is estimated. For 1988 onward, the assumption is made that all spawning events are surveyed and the spawn index provides an unbiased estimate of spawning abundance (ie. q=1). Age-composition data are portioned into three fishery periods; a seine roe fishery, a gillnet roe fishery, and a winter fishery. The winter fishery and seine roe fishery are treated as non-selective for all available fish. For the gillnet fishery, size-specific selectivity is estimated. Availability, selectivity, and natural mortality are allowed to vary over time. For details of specific parameterizations and other aspects of the model readers are referred to Haist and Schweigert (2006) and Schweigert and Haist (2007). The HCAM version R20 model was selected for the 2006 herring stock assessments because it had superior performance in retrospective analyses (Table 1), relative to other model formulations.

Table 1. Summary statistics for retrospective changes in stock biomass estimates from the HCAM R20 model runs for the five herring stocks. [updated from table 3 in Schweigert & Haist (2007)]

	$100\left(B_y^{2005} - B_y^y\right)/B_y^{2005}$								
Stock	*Mean*	1998	1999	2000	2001	2002	2003	2004	2005
GS	-12.9	16.5	11.5	-11.0	3.0	-30.8	-18.5	-37.5	-6.3
WCVI	-10.1	-21.2	-6.9	2.3	-0.2	10.4	-34.6	-29.5	-1.6
CC	-15.2	16.1	-18.1	-6.4	3.7	-6.7	-9.6	-19.0	-39.0
PRD	-17.1	20.6	14.1	-0.1	-0.6	-42.7	-28.8	-17.3	-24.8
QCI	-1.9	3.9	-8.8	0.2	5.4	-14.3	1.7	0.1	0.2

While the 2006 stock assessments were based on posterior distributions rather than MPD estimates, conducting fully Bayesian analyses is not feasible (because of computing power limitations). For the herring stock assessments the MPD estimates appear to be unbiased (Schweigert and Haist 2007), so this approach is not unreasonable.

The key outputs evaluated are estimated abundance in 2006 and stock projections for 2007. The calculation of potential 2007 harvest uses the guidelines currently in place for herring management. That is, a 20% harvest rate is assumed unless the stock is close to the CUTOFF level, in which case the potential harvest is reduced to the difference between the forecast abundance and the CUTOFF. Forecast pre-fishery abundance is based on the estimated biomass of fish aged 4 and older fish and estimates of 3-year-old recruitment. Recruitment of 3 year-old fish is assumed to be AVERAGE (mean of the middle third of historical estimates), unless:

1. If the pre-fishery biomass was below CUTOFF in the previous year, then assume POOR recruitment for the forecast (mean of the lower third of historical estimates).
2. If the pre-fishery biomass was above CUTOFF in the previous year and recruitment has been GOOD in the two previous years, then assume GOOD recruitment for the forecast (mean of the upper third of historical estimates).

2.1 Biological Sampling Data

A comprehensive program for collecting biological samples from commercial herring fisheries has been in place since 1950. Prior to that time, there was some sampling effort but it did not encompass the full geographic and temporal range of the fisheries. Exploitation rates were high during the reduction era (pre-1970) fisheries, and the fishery sampling programs provided a comprehensive picture of the populations vulnerable to the fisheries. In contrast, the roe herring fisheries that developed in the 1970s and continue today tend to be geographically and temporally restricted. A charter program provides biological samples of the spawning stocks that encompass a broader range of the vulnerable populations. In areas where there are fishery closures, charter program biological samples are the only source of information about the age-composition of the stock.

The herring stock assessments utilize biological samples collected from both the commercial fisheries and the charter programs for age composition and size-at-age data. For the analyses reported here, we define *high effort* biological sampling as that represented by the current program. We define a *low effort* biological sampling program as one that collects and processes only samples from the commercial fisheries. That is, for a *low effort* sampling program we assume there will be no samples from the charter program.

Ages are determined for virtually all herring that are sampled, so age-length keys are not used to generate age-composition data. Rather, the age compositions for all relevant samples are aggregated to generate the overall age composition for each of: the seine roe fishery period, the gillnet roe fishery period, and the winter fishery period. For the *low effort* biological sampling scenario we exclude all samples that were collected from the charter fishery program in the data aggregation. This primarily impacts the seine roe fishery period.

We examine two scenarios assuming different years when the transition to *low* sampling coverage occurs: 1) a 2002 *transition year* and, 2) a 1997 *transition year*. For these scenarios, we replace the age-composition and size-at-age data in the 2006 stock assessment data files for the *transition year* and all later years with fishery sampling data only. Exclusion of charter samples primarily changes the number of fish sampled in the seine roe fishery period (Table 1). Note that although the effective number of sampled fish used in the assessment model is reduced, this has little impact on the relative weight of the age composition and biological sampling data. The weighting of the age composition data in the assessment model results from both sampling and process error, where sampling error is related to the number of fish sampled and process error is a fixed value. The much larger effect is from the process error (Haist and Schweigert 2006), so the reduced sample sizes that result from removing charter samples has little effect on the relative data weighting.

Table 1. Number of fish in the age-composition samples when all data is used (*high* sampling effort) and when charter samples are excluded (*low* sampling effort). Numbers are presented by stock and year (1997-2006) for the three fishery categories (Seine Roe, Gillnet Roe, and Winter) used in the stock assessments.

Stock		All data			Excluding charter samples		
	year	Winter	Sn-Roe	Gn-Roe	Winter	Sn-Roe	Gn-Roe
QCI	1997	0	1742	0	0	0	0
	1998	0	2792	0	0	1256	0
	1999	0	2516	601	0	1562	601
	2000	0	2245	0	0	1104	0
	2001	0	1393	0	0	0	0
	2002	0	3325	0	0	875	0
	2003	0	2472	0	0	0	0
	2004	0	1224	0	0	0	0
	2005	0	1309	0	0	0	0
	2006	0	736	0	0	0	0
PRD	1997	0	2698	631	0	0	631
	1998	0	2480	1082	0	0	1082
	1999	0	1690	721	0	0	721
	2000	0	3972	811	0	931	811
	2001	0	3941	1040	0	939	1040
	2002	0	4422	1059	0	1129	1059
	2003	0	4248	870	0	924	870
	2004	0	2432	1117	0	571	1117
	2005	0	2972	754	0	623	754
	2006	0	2001	577	0	338	577
CC	1997	0	6871	514	0	908	514
	1998	0	6571	1031	0	1375	1031
	1999	0	5005	927	0	928	927
	2000	0	4527	685	0	1275	685
	2001	0	4415	800	0	1166	800
	2002	0	5794	504	0	1159	504
	2003	0	4714	925	0	874	925
	2004	0	3311	0	0	455	0
	2005	0	6394	0	0	1353	0
	2006	0	5835	0	0	604	0
GS	1997	275	7768	633	0	800	633
	1998	1599	8970	1398	0	874	1398
	1999	1374	4352	836	0	962	836
	2000	1077	7578	1179	0	1026	1179
	2001	797	6864	1027	0	918	1027
	2002	928	6112	915	0	909	915
	2003	804	9115	1354	0	1011	1354
	2004	551	5209	1185	0	636	1185
	2005	249	4966	773	0	838	773
	2006	511	5202	904	0	676	904
WCVI	1997	0	5994	0	0	818	0
	1998	0	5444	899	0	967	899
	1999	0	4351	1043	0	1165	1043
	2000	0	5014	625	0	700	625
	2001	0	2352	0	0	0	0
	2002	0	5072	535	0	0	535
	2003	0	5316	700	0	1130	700
	2004	0	5544	631	0	426	631
	2005	0	3756	581	0	432	581
	2006	0	1154	0	0	0	0

2.2 Spawn surveys

The spawn survey program is comprised of two key components, 1) identification of locations where spawning events have occurred, and 2) assessment of the length, the width and the average egg density to estimate the total egg deposition. Generally, locations of spawning events are identified by periodic fixed wing over-flights of potential spawning areas and diver-based methods are used to survey the identified spawns. Reductions in resources for spawn surveys could impact both the fraction of spawn events that are identified and the quality of the spawn surveys. Surveys could be impacted by not surveying all spawns, using surface-based methods to replace dive methods for some or all spawn events, or reducing the dive-survey effort on spawns (ie. fewer transects sampled). Missing spawn events, either because they are not identified or because they are not surveyed, will introduce bias to the spawn data. Reductions in data quality will increase the variance of the observations. We capture both of these components in the alternative data sets.

The simulation procedure we use assumes there is a *transition year* in which the spawn survey program is modified to a lower level of sampling effort and this level of effort continues in following years. We assume that the 2006 stock assessment estimates of spawning abundance reflect the "true" populations. For years from 1951 to the *transition year*, the actual spawn observations are used. For the *transition year* and all later years spawn observations are simulated, based on the true spawn estimates and different levels of variance and bias in the observations.

Variance estimates for simulating spawn data are based on residuals from the data fits estimated for the 2006 stock assessment analyses. Prior to 1988, spawn surveys were conducted using surface survey methods, a survey method that generates spawning biomass estimates with relatively low precision. After 1988, the majority of spawns were surveyed using dive methods and we assume these will have relatively high precision. The variance of spawn residuals estimated for the 2006 assessment model runs, were calculated for the periods, 1951 to 1987 and 1988 to 2006 (Table 2). We use these to reflect the random error associated with *low* and *high* survey effort, respectively. We define a *moderate* level of spawn survey effort as one with variances mid-way between the *high* and *low* effort values.

Table 2. The standard deviation of spawn residuals (ln[observerd/true]) from the 2006 herring stock assessments, by stock and period.

	St. Dev. of residuals	
	1951-1987	1988-2006
QCI	0.508	0.235
PRD	0.551	0.250
CC	0.441	0.226
GS	0.306	0.290
WCVI	0.390	0.217

We have no objective basis for selecting values for the proportion of spawning stock biomass that would be missed with reduced survey effort. We arbitrarily assume that a *high* level of spawn survey effort will ensure all spawn events are surveyed and that a *low* level of effort will survey between 60% and 100% of the spawn events. We assume a uniform distribution for the proportion of spawning biomass surveyed, and that survey effort at a *moderate* level is intermediate between the *low* and *high* levels.

As for the biological sampling program, we investigate the effects of changes to the spawn survey program that occur at various *transition years*. The transition years examined are 2006, 2002 and 1997, which require replacement of the last one, five, and ten years of spawn survey data, respectively. The spawn data observations used in the replicate data sets are generated as follows:

$$S_y^P = S_y^O \qquad y < transition year$$
$$S_y^P = f_y\left(S_y^T \exp\left(e_y\right)\right) \qquad y \geq transition\ year$$

where S_y^O is the observed spawn in year y,
S_y^T is the true spawn in year y (model estimates from the 2006 assessments),
S_y^P is the simulated spawn in year y,
l_1, l_2 specify the range in the proportion of egg deposition surveyed,
s^2 is the variance of the spawn error terms,
f_y~U$[l_1, l_2]$, and e_y~N$[0, s^2]$.

Parameter values used to simulate spawn observations for the *low*, *moderate*, and *high* survey effort levels are shown in Table. 3.

For each combination of survey effort level (*low, moderate*, and *high*) and *transition year* (2006, 2002 and 1997), 100 replicate data sets were generated and run through the stock assessment model. The key outputs evaluated are estimated abundance in 2006 and stock projections for 2007. Results were summarized across the 100 replicates.

Table 3. Parameters used to simulate alternative spawn data (standard deviations of error and range in the proportion surveyed) for the five BC herring stocks and three levels of survey effort.

	Std. dev of error (s)			Proportion surveyed (l_1, l_2)		
	Survey effort			Survey effort		
Stock	*high*	*moderate*	*Low*	*high*	*moderate*	*low*
QCI	0.235	0.371	0.508	1	0.8-1.0	0.6-1.0
PRD	0.250	0.400	0.551	1	0.8-1.0	0.6-1.0
CC	0.226	0.333	0.441	1	0.8-1.0	0.6-1.0
GS	0.290	0.289	0.306	1	0.8-1.0	0.6-1.0
WCVI	0.217	0.304	0.390	1	0.8-1.0	0.6-1.0

3 RESULTS

3.1 Biological Sampling Data

Assessment model runs that were based on the *low effort* biological sampling data sets result in only minor changes to estimates of the 2006 spawning biomass, with the largest difference, 9%, estimated for the Georgia Strait stock with a 2002 *transition year* (Table 4). The changes to the 2007 biomass forecasts are larger, generally differing from the *base case* estimates by 10 to 20%. For potential harvest estimates, differences are similar to those of the forecast biomass except for stocks that are forecast close to or below the CUTOFF level. For the two stocks with *base case* forecasts below their CUTOFF levels, the alternative data sets have no effect on the potential harvest. For the CC stock, with a base case forecast that is marginally above the CUTOFF, the effect of the alternative data sets is large, decreasing the potential harvest level to 49% and 26% of the base case value for the 2002 and 1997 *transition years*, respectively.

The reason that the 2006 spawning biomass estimates are less affected by the alternative data sets than the 2007 biomass forecasts results from using the spawning biomass data as absolute abundance estimates. Thus spawning biomass is relatively well determined, while other model parameters that influence the stock reconstructions are less well determined. For example, recruitment estimates for some of the stocks change substantially when the alternative data sets are used (Figure 1). For the WCVI stock all recruitment estimates are reduced by about 30%, and this is compensated with changes in the natural mortality estimates. Hence, stock projections can change substantially even though there is little change to spawning biomass estimates.

Table 4. Model estimates of 2006 spawning biomass, 2007 biomass forecast and potential harvest for the *base case* assessments and analyses using the *low* biological sampling effort data sets with transition years 2002 and 1997, for the five BC herring stocks.

			Model estimates			Ratio of alternative estimate to Base case estimate		
Stock	*Transition year*	CUTOFF	2006 Spawning Biomass	2007 Forecast Biomass	Potential Harvest	2006 Spawning Biomass	2007 Forecast Biomass	Potential Harvest
QCI	*Base case*	10700	5838	6740	0			
	2002		5910	8192	0	1.01	1.22	1.00
	1997		5884	5818	0	1.01	0.86	1.00
PRD	*Base case*	12100	14116	20017	4003			
	2002		14025	20355	4071	0.99	1.02	1.02
	1997		13912	18154	3631	0.99	0.91	0.91
CC	*Base case*	17600	14906	19685	2085			
	2002		14952	18620	1020	1.00	0.95	0.49
	1997		14911	18145	545	1.00	0.92	0.26
GS	*Base case*	21200	54490	73514	14703			
	2002		59379	83603	16721	1.09	1.14	1.14
	1997		59009	81209	16242	1.08	1.10	1.10
WCVI	*Base case*	18800	2777	13987	0			
	2002		2860	11412	0	1.03	0.82	1.00
	1997		2867	11893	0	1.03	0.85	1.00

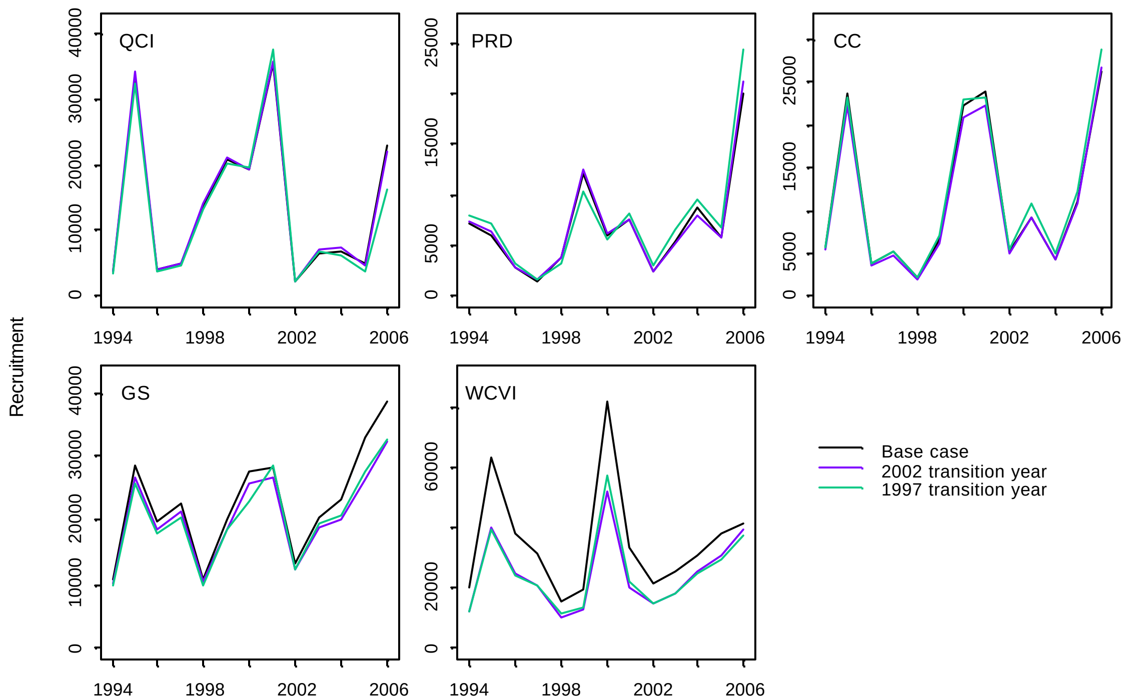

Figure 1. Model estimates of recruitment (1994-2006) from base case assessments and analyses using the low biological sampling effort data sets and transition years 2002 and 1997, for the five BC herring stocks.

3.2 Spawn Survey Data

Model runs based on the *high* spawn survey effort data sets show little bias in the median estimates of 2006 spawning stock biomass relative to the 2006 *base case* MPD estimates (Figure 2). This result is consistent with the 2006 stock assessments where the medians of the marginal posterior distributions (from MCMC analyses) of 2006 spawn biomass were unbiased relative to their MPD estimates (Schweigert and Haist 2007). The uncertainty in the estimates, as indicated by the central 90% of the range of bootstrap replicates, is somewhat smaller than that estimated for the 2006 stock assessment using Bayesian estimation. This is expected, given we resample only the terminal years spawn data and do not consider uncertainty in the age-composition data. The model runs based on the *high* spawn survey effort underestimate the full uncertainty, but they are useful as reference points when evaluating the impact of the *moderate* or *low effort* spawn survey assumptions.

For model runs using the *moderate* and *low* spawn survey effort data series, estimates of 2006 spawning stock biomass were biased, and the level of bias was consistent with the degree of bias assumed in the simulations (Figure 2, Table 5). That is, the expected values for the proportion of spawns surveyed are 0.8 and 0.9 for the *low* and *moderate effort* spawn survey data series, respectively, and these values are similar to the average bias observed across the 5 stocks (Table 5). For the *low effort* spawn survey analyses with a 2006 transition year the bias in 2006 spawning stock biomass estimates was somewhat lower than the simulated level (0.84 versus 0.80), likely because the age-composition data provides additional information about stock trends. Also, variability of the 2006 spawning stock biomass estimates increases with lower levels of spawn survey effort, but the variability does not appear to be affected by the number of years with lower quality spawn survey data (Table 5).

Bias in the forecasts of 2007 pre-fishery biomass are less impacted by the lower quality spawn survey data than are the estimates of 2006 spawning stock biomass (Table 5), although this is variable among the stocks. This suggests that there may be compensation in the model for bias in the spawn survey data. That is, other model parameters such as natural mortality and availability rates may be modified so that reduced spawning stock biomass estimates do not fully translate into reduced abundance forecasts. In addition to the lower bias in the abundance forecasts, the variability in these estimates are also lower than those in the 2006 spawning biomass estimates (Table 5).

Table 5. Median and c.v. of 2006 spawning stock biomass and 2007 forecast biomass ratios (relative to base case estimates) by stock and transition year for 3 levels of sampling effort in the spawn survey program. For each statistic, means across the 5 stocks are also presented. Runs were conducted with *high effort* biological sampling data.

Statistic		Stock	Transition year								
			2006	2002	1997	2006	2002	1997	2006	2002	1997
			High			Moderate			Low		
2006 spawning biomass	Median	QCI	0.99	1.00	0.99	0.89	0.90	0.91	0.81	0.89	0.80
		PRD	0.98	1.02	1.04	0.88	0.93	0.95	0.84	0.70	0.80
		CC	1.00	1.00	1.01	0.90	0.89	0.87	0.85	0.84	0.77
		GS	0.97	1.01	1.03	0.88	0.91	0.93	0.85	0.76	0.79
		WCVI	0.99	1.01	1.00	0.88	0.93	0.90	0.85	0.83	0.77
		Mean	0.99	1.01	1.01	0.89	0.91	0.91	0.84	0.80	0.79
2006 spawning biomass	C.V.	QCI	0.25	0.27	0.22	0.42	0.44	0.35	0.49	0.46	0.54
		PRD	0.18	0.18	0.21	0.31	0.31	0.35	0.45	0.47	0.44
		CC	0.21	0.24	0.21	0.32	0.37	0.30	0.37	0.36	0.40
		GS	0.19	0.20	0.22	0.22	0.22	0.26	0.25	0.28	0.28
		WCVI	0.23	0.25	0.22	0.34	0.36	0.30	0.39	0.37	0.44
		Mean	0.21	0.23	0.22	0.32	0.34	0.31	0.39	0.39	0.42
2007 forecast biomass	Median	QCI	1.00	1.07	1.06	0.95	0.97	0.95	0.92	1.01	0.93
		PRD	0.98	1.01	1.06	0.89	0.95	0.98	0.86	0.79	0.85
		CC	1.00	1.00	1.00	0.92	0.93	0.92	0.88	0.91	0.82
		GS	0.98	1.02	1.04	0.91	0.95	0.97	0.89	0.85	0.87
		WCVI	1.00	0.98	1.02	0.99	0.96	1.00	0.99	0.96	0.92
		Mean	0.99	1.02	1.04	0.93	0.95	0.96	0.91	0.90	0.88
2007 forecast biomass	C.V.	QCI	0.22	0.23	0.22	0.28	0.31	0.28	0.31	0.33	0.37
		PRD	0.16	0.16	0.19	0.28	0.26	0.31	0.41	0.41	0.40
		CC	0.18	0.20	0.17	0.27	0.30	0.24	0.32	0.31	0.34
		GS	0.15	0.14	0.16	0.16	0.15	0.18	0.18	0.18	0.19
		WCVI	0.02	0.16	0.13	0.02	0.22	0.19	0.03	0.27	0.24
		Mean	0.15	0.18	0.17	0.20	0.25	0.24	0.25	0.30	0.31

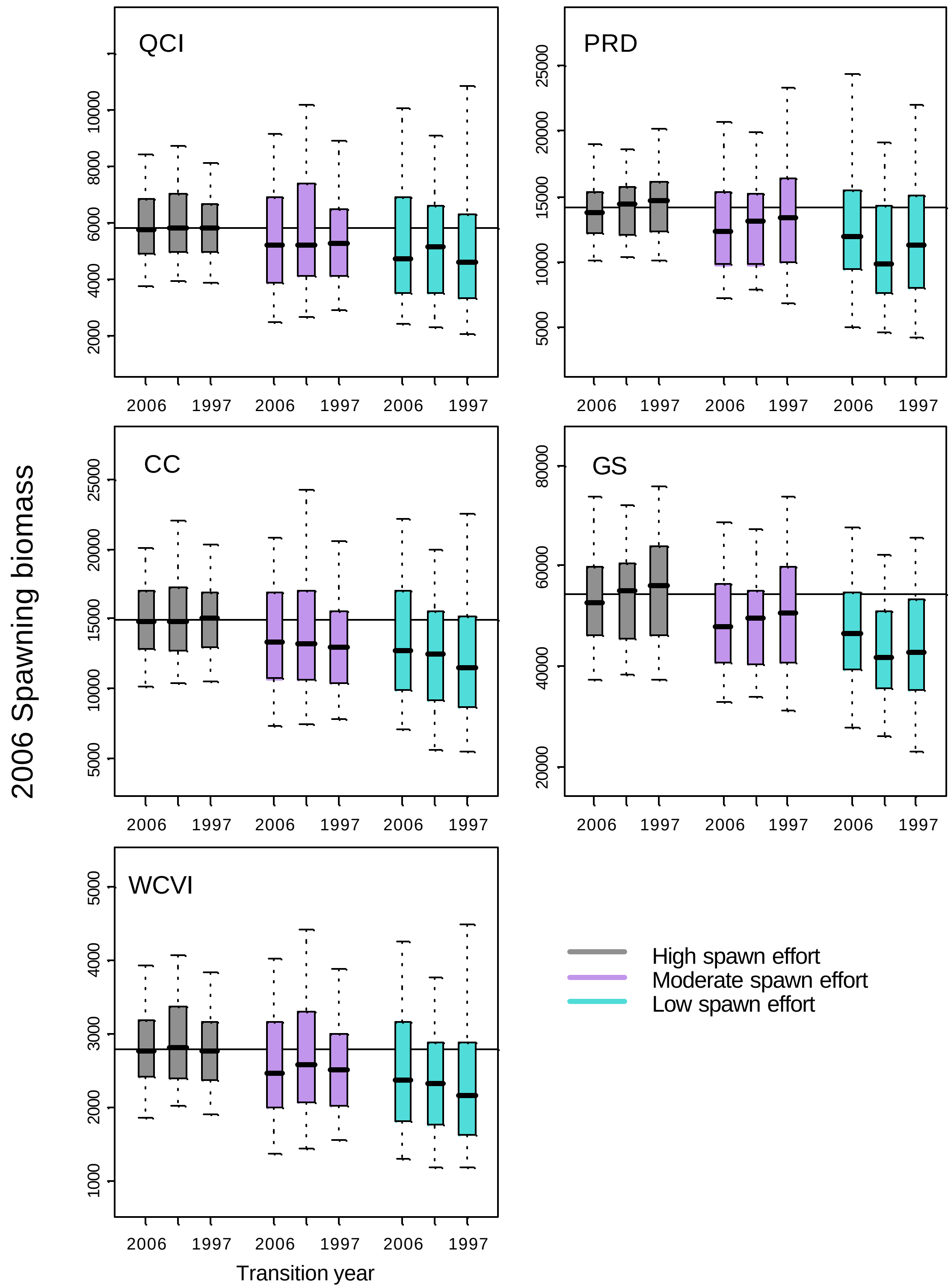

Figure 2. Distributions of 2006 spawning stock biomass estimates for assessments run with alternative data sets assuming *high, moderate*, and *low* spawn survey effort programs and transition years of 2006, 2002, and 1997. Boxes indicate the interquartile ranges, solid bars indicate the medians, and whiskers indicate the 5th and 95th percentiles of the distributions. The solid lines show the MPD values from the 2006 *base case* stock assessments.

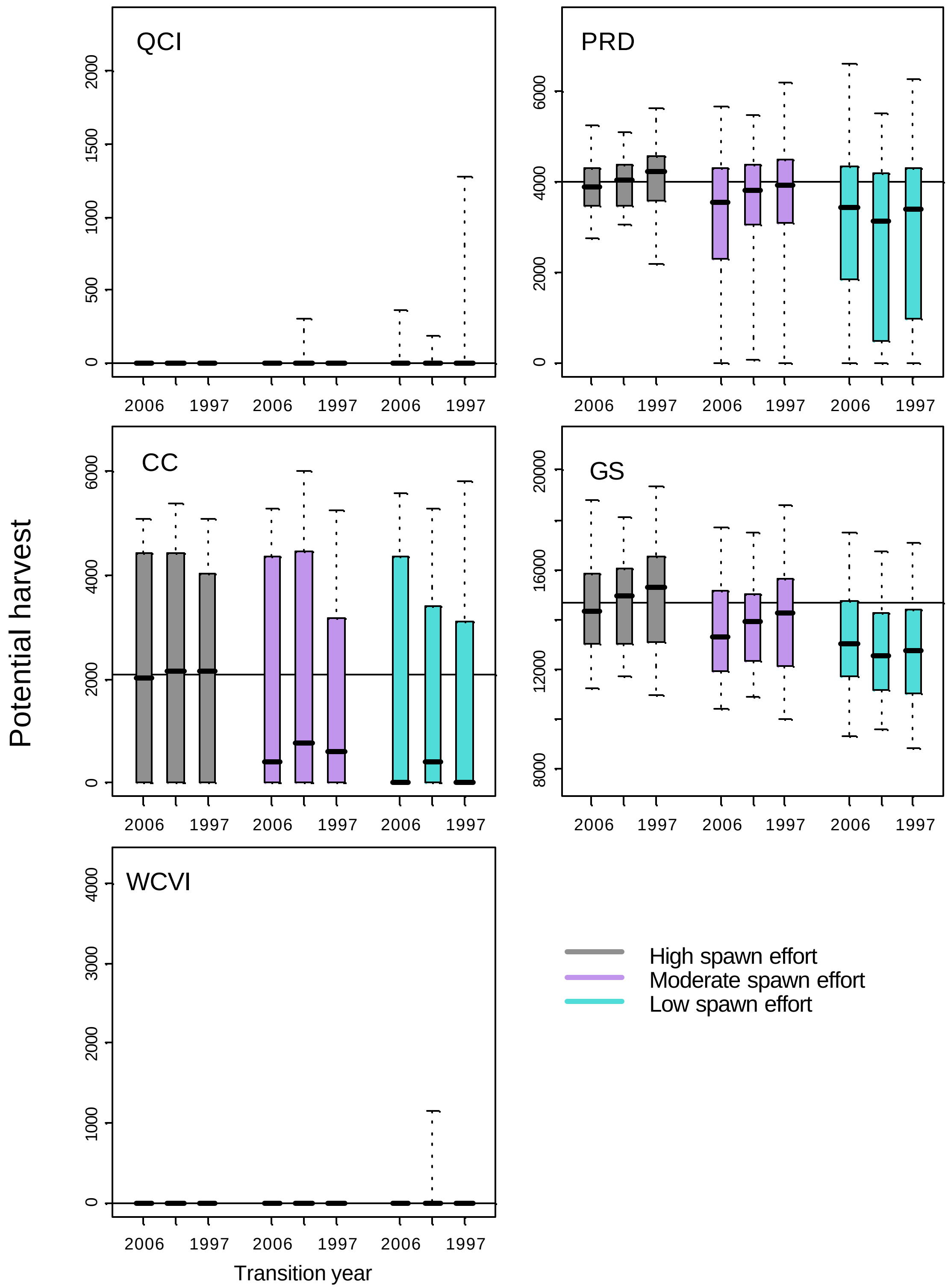

Figure 3. Distributions of 2007 potential harvest estimates for assessments run with alternative data sets assuming *high, moderate*, and *low* spawn survey effort programs and transition years of 2006, 2002, and 1997. Boxes indicate the interquartile ranges, solid bars indicate the medians, and whiskers indicate the 5th and 95th percentiles of the distributions. The solid lines show the MPD values from the 2006 *base case* stock assessments.

For the PRD and GS stocks, bias in the forecasts of 2007 pre-fishery biomass translate directly into bias in the potential harvest (Figure 3). For the CC stock, which is close to it's CUTOFF level, the effect of bias in the spawn survey data potentially has a larger impact on the potential harvest. The 2006 *base case* stock assessments resulted in no potential harvest for the QCI and WCVI stock, because they were forecast to be below their CUTOFF levels. For model runs with *moderate* and *low effort* spawn survey data the probability of potential harvest in 2007 increased (Table 6). For the PRD and CC stocks the probability of no potential harvest increased with *moderate* and *low* spawn survey effort programs, and only the GS was potentially immune to a fishery closure.

Table 6. Percent of trials that had no potential harvest for *high* and *low* biological sampling effort, *high, moderate and low* spawn survey effort and alternative *transition years*.

Biological sampling effort	Spawn survey effort	Transition Year	QCII	PRD	CC	SG	WCVI
	2006 Base Case		No harvest	Harvest	Harvest	Harvest	No harvest
High	High	1997	98	1	28	0	99
		2002	96	0	31	0	98
		2006	99	0	26	0	100
	Moderate	1997	96	7	45	0	95
		2002	93	5	45	0	96
		2006	96	8	47	0	100
	Low	1997	90	19	61	0	95
		2002	94	23	47	0	89
		2006	93	19	53	0	100
Low	High	1997	100	2	41	0	100
		2002	100	1	45	0	100
		2006	100	1	44	0	100
	Moderate	1997	99	10	58	0	100
		2002	98	10	56	0	99
		2006	99	11	57	0	100
	Low	1997	96	21	66	0	100
		2002	98	28	62	0	99
		2006	97	23	63	0	100

3.3 Biological sampling and spawn survey programs

The runs conducted to evaluate potential impacts of alternative levels of effort for the spawn survey program all assumed the *high* level of effort for the biological sampling program (ie. all sampling data used). The various combinations of *transition year* and spawn survey sampling effort were also run for the *low* biological sampling effort to investigate the potential effect of changes in both programs.

In general, the effect of lower quality biological sampling data in addition to lower quality spawn survey data is cumulative. That is, the bias resulting from each is additive when the two are combined. As was the case where only the biological sampling data was modified, estimates of 2006 spawning stock biomass are not greatly different for the *low* and *high* biological sampling runs (Figure 4, Table 7). The exception is for the GS stock where there is

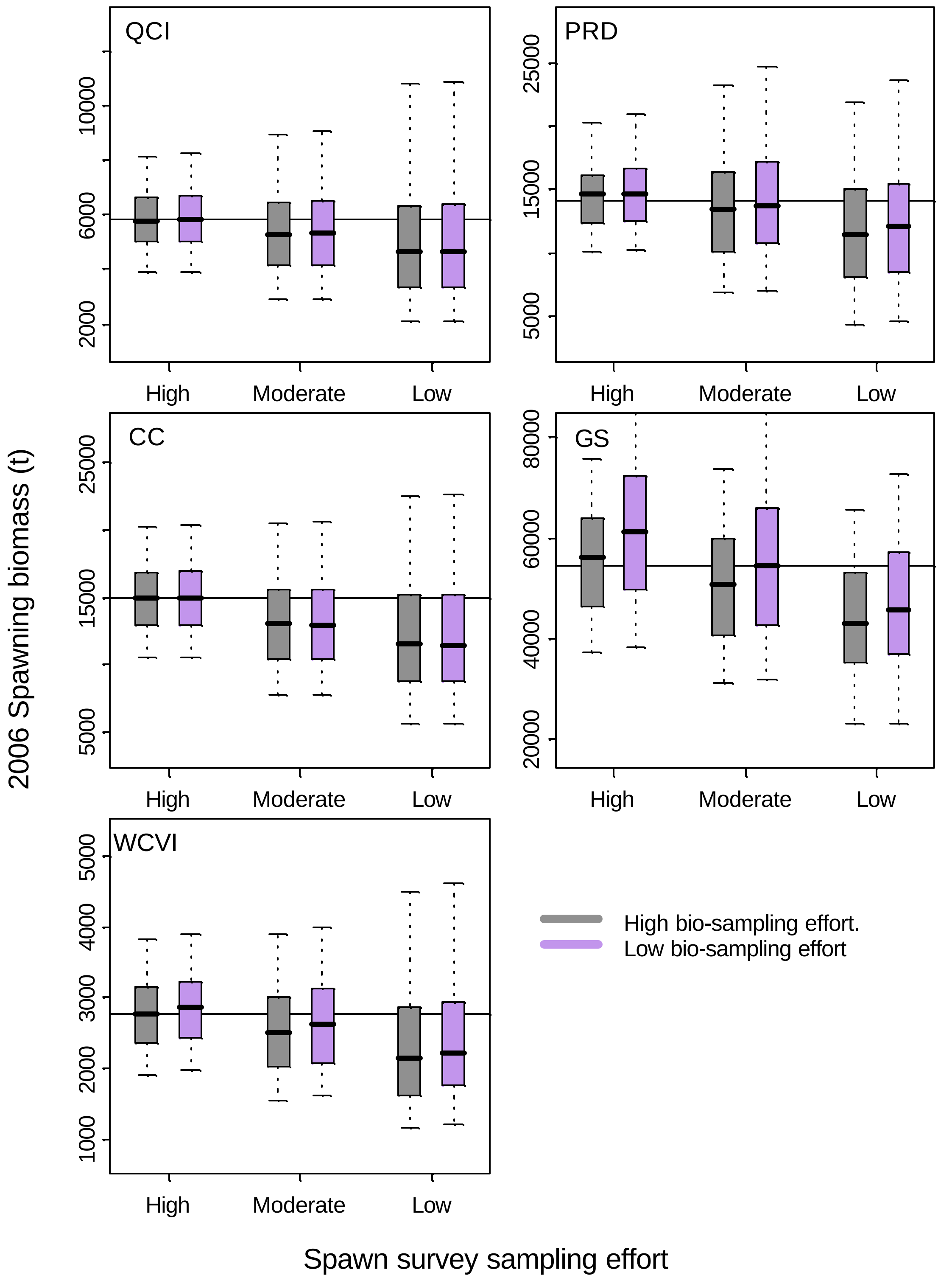

Figure 4. Distributions of 2006 spawning stock biomass estimates for assessments run with alternative data sets assuming *high, moderate*, and *low* spawn survey effort and *high* and *low* biological sampling programs and a 1997 transition year. Boxes indicate the interquartile ranges, solid bars indicate the medians, and whiskers indicate the 5th and 95th percentiles of the distributions. The solid lines show the MPD values from the 2006 *base case* stock assessments.

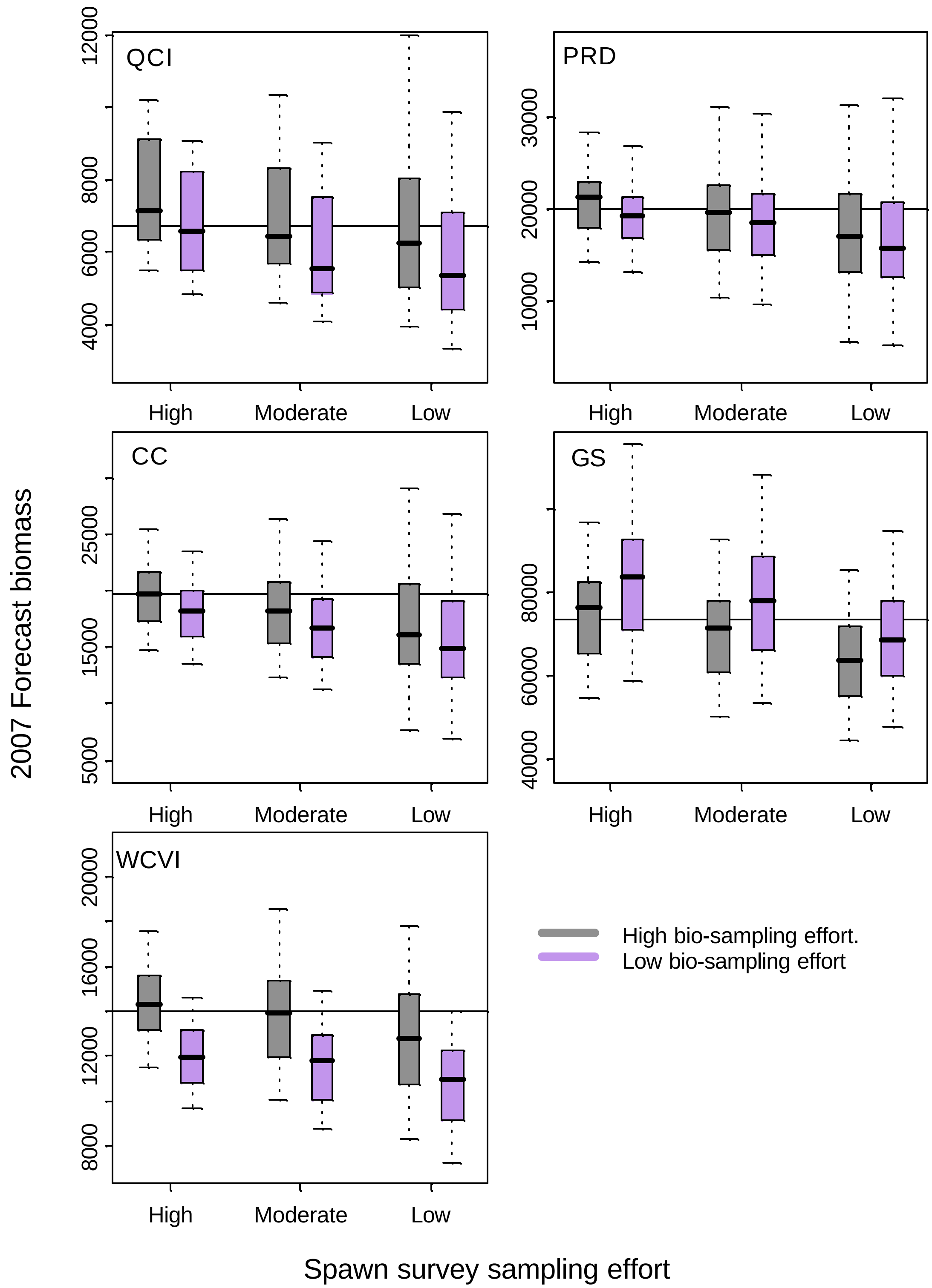

Figure 5. Distributions of 2007 forecast biomass estimates for assessments run with alternative data sets assuming *high, moderate,* and *low* spawn survey effort and *high* and *low* biological sampling programs and a 1997 transition year. Boxes indicate the interquartile ranges, solid bars indicate the medians, and whiskers indicate the 5th and 95th percentiles of the distributions. The solid lines show the MPD values from the 2006 *base case* stock assessments.

positive bias with the *high* spawn survey effort data sets, and this tendency for a positive bias compensates for the negative bias from the *moderate* and *low* spawn survey data sets.

The 2007 stock forecasts are more strongly affected by the *low* quality bio-sampling data than are the 2006 spawning stock biomass estimates. For 4 of the 5 herring stocks the negative bias in stock forecasts that results from biased spawn survey data increases when there is *low effort* biological sampling data (Figure 5). For the GS stock, bias caused by the *low effort* biological data partially compensates the bias from the spawn survey data. The variability of the stock forecasts does not increase with the *low effort* biological sampling data relative to the *high effort* biological sampling data (Figure 5), however, the probability of no potential harvest increases for the CC and PRD stocks (Table 6).

Table 7. Median and c.v. of 2006 spawning stock biomass and 2007 forecast biomass ratios (relative to base case estimates) by stock and transition year for 3 levels of sampling effort in the spawn survey program. For each statistic, means across the 5 stocks are also presented. Runs were conducted with *low effort* biological sampling data.

			Transition year								
			2006	2002	1997	2006	2002	1997	2006	2002	1997
Statistic		Stock	High			Moderate			Low		
2006 spawning biomass	Median	QCI	1.00	1.01	1.00	0.90	0.91	0.91	0.81	0.89	0.80
		PRD	0.97	1.01	1.03	0.88	0.94	0.97	0.84	0.74	0.85
		CC	1.00	1.00	1.01	0.90	0.89	0.87	0.85	0.84	0.77
		GS	1.04	1.13	1.12	0.93	0.97	1.00	0.90	0.80	0.84
		WCVI	1.03	1.06	1.03	0.92	0.98	0.94	0.88	0.89	0.80
		Mean	1.01	1.04	1.04	0.91	0.94	0.94	0.86	0.83	0.81
2006 spawning biomass	C.V.	QCI	0.25	0.27	0.22	0.42	0.45	0.36	0.49	0.46	0.54
		PRD	0.19	0.19	0.22	0.32	0.32	0.36	0.48	0.49	0.45
		CC	0.21	0.24	0.21	0.33	0.37	0.30	0.38	0.36	0.41
		GS	0.25	0.25	0.28	0.26	0.26	0.30	0.30	0.31	0.31
		WCVI	0.23	0.24	0.21	0.33	0.35	0.29	0.38	0.36	0.43
		Mean	0.23	0.24	0.23	0.33	0.35	0.32	0.41	0.40	0.43
2007 forecast biomass	Median	QCI	0.86	0.95	0.98	0.83	0.87	0.82	0.80	0.93	0.80
		PRD	0.89	0.92	0.96	0.82	0.87	0.93	0.79	0.75	0.79
		CC	0.92	0.92	0.93	0.84	0.86	0.85	0.81	0.84	0.75
		GS	1.07	1.13	1.14	0.99	1.03	1.06	0.97	0.92	0.93
		WCVI	0.85	0.84	0.86	0.84	0.82	0.84	0.83	0.84	0.78
		Mean	0.92	0.95	0.97	0.86	0.89	0.90	0.84	0.86	0.81
2007 forecast biomass	C.V.	QCI	0.23	0.23	0.22	0.28	0.31	0.28	0.31	0.32	0.35
		PRD	0.17	0.16	0.20	0.29	0.26	0.32	0.43	0.43	0.42
		CC	0.18	0.20	0.17	0.27	0.30	0.24	0.32	0.30	0.35
		GS	0.18	0.18	0.20	0.19	0.18	0.20	0.21	0.20	0.21
		WCVI	0.03	0.16	0.13	0.05	0.21	0.18	0.07	0.25	0.20
		Mean	0.16	0.19	0.18	0.22	0.25	0.24	0.27	0.30	0.31

4 Discussion

The Monte-Carlo approach used to generate alternative spawn survey data sets is a bootstrap method (Efron and Tibshirani 1998) that has often been used to investigate uncertainty in fisheries stock assessments (Smith et al. 1993, and papers therein). In general when using a conditional parametric bootstrap approach (Smith et al. 1993) all key assessment data are re-sampled to generate the replicate data sets (eg Garvaris 1993). We modified the standard bootstrap approach and re-sampled only a subset of the data, to allow us to investigate potential effects of changes in the data collection programs. This was a pragmatic solution that avoided the complexity of developing a full operating model of BC herring stock, fishery and data collection dynamics.

Results of the simulations presented in this document allow some general conclusions about the potential impacts of reductions in bio-sampling and spawn survey program effort on herring stock assessments and management advice. Program changes that effect only the bio-sampling data would likely have relatively minor impact on estimates of spawning stock biomass but would have greater effects on stock forecasts and estimates of potential yields. There is no obvious bias in the changes to stock forecasts from reduced bio-sampling effort, so estimates could either over or under-estimate true values.

The simulations evaluating reduced effort for spawn survey programs introduce a negative bias to the spawn survey data. The simulated data biases translate into comparable levels of negative bias in estimates of spawning abundance, but somewhat smaller bias in stock forecasts. The use of a model that synthesizes both the spawn and age-composition data, in conjunction with using the spawn survey data as an absolute estimate, appears to allow some compensation when there is a relatively small amount of biased data.

When simulations included both bio-sampling and spawn survey data quality effects, the impact on spawning stock biomass estimates was similar to analyses where only spawn survey data quality effects were simulated. However, the stock forecast estimates were more strongly affected and had larger negative biases than when only reduced spawn survey data quality was simulated.

The question arises, would retrospective patterns in the stock assessments contaminate the results and conclusions of these analyses. This seems unlikely, given the procedures used for this analysis. For the analyses with lower effort biological sampling data, the only information that potentially changes relates to the relative year-class strengths. While four of the five stocks tend to have negative retrospective bias (all but QCI), there were both negative and positive biases in stock forecasts when lower effort biological sampling data was used. For the analyses with lower effort spawn survey data, bias in terminal year and forecast biomass was consistent across all stocks. Given that the QCI stock shows virtually no retrospective bias, different results would be expected for this stock relative to the others, if retrospective bias were a significant contributor to the observed patterns.

Results of the simulations presented in this document are primarily intended for illustrative purposes. We are not attempting to quantify the direct effect of various levels of sampling effort on stock assessments and management advice, rather to demonstrate that reductions in sampling effort will impact the assessments and advice. Evaluation of the trade-offs between sampling effort (and associated costs) and stock assessment precision and accuracy which would allow development of minimal data collection standards is beyond the scope of this analysis. Analyses to pursue those objectives would require development of a fully prescribed operating model.

A fully prescribed operating model requires: 1) specification of the stock and fishery dynamics and their associated uncertainties, 2) specification of the sampling data including bias and uncertainty relative to the stock and fishery dynamics, and 3) specification of the management strategy and implementation errors. Of these items, the first and last should be relatively straight forward to deal with. The HCAM model used for the herring stock assessments allows for considerable flexibility in assumptions about stock and fishery dynamics for both conditioning to historical data and simulating future conditions. The current 20% harvest rate with stock-specific CUTOFF levels could be the basis for the management strategy and implementation uncertainly and error could be based on historical patterns. A greater difficulty lies in specifying the potential bias and uncertainty in sampling data, relative to the stock and fishery dynamics. Even in the best of situations, fisheries sampling is unlikely to follow standard random sampling assumptions. Likely there are biases and autocorrelation in the processes, which would be accentuated with reductions in sampling coverage.

We make two specific recommendations that will facilitate future work to address questions such as the optimal use of sampling resources and minimum sampling requirements. These are:

1. Changes to and limitations of the herring sample collection programs, including reductions in geographical and temporal effort, should be documented. In particular un-surveyed spawns should be documented, even where these are based on anecdotal information.

2. A group of individuals, knowledgeable in herring fisheries and simulation methodology, should be tasked with developing specifications for the data-sampling component of an operating model. The sampling component will have the largest effect on results relative to sampling strategies, and this component should be agreed to prior to any further work to investigate sampling strategies being undertaken. Ideally, the full specifications of the operating model would be reviewed by PSARC before final analyses are conducted.

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