Treatment and effects of Pacific halibut discard mortality (bycatch) in non-directed fisheries projected for 2019

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Purpose

This document provides a response to the request from the Commission for more information on the role of Pacific halibut discard mortality (a.k.a. bycatch), from non-directed fisheries, in IPHC analyses and results using the data available at the 94th Session of the IPHC Interim Meeting (IM094). The topics addressed include:

Topic 1: How discard mortality (a.k.a. bycatch) from non-directed fisheries (both U26 and O26) is included in the stock assessment.

Topic 2: How discard mortality (a.k.a. bycatch) from non-directed fisheries (both U26 and O26) is included in the IPHC's Interim Management Procedure at the coastwide level and by individual IPHC Regulatory Area.

Topic 3: How projected levels of discard mortality (a.k.a. bycatch) from non-directed fisheries for 2019 (both U26 and O26) effect the yield available to the directed Pacific halibut fisheries at the coastwide level and by individual IPHC Regulatory Area.

Summary

Pacific halibut captured in fisheries where retention of any Pacific halibut is prohibited are considered to be bycatch. Given Commissioners are used to the term bycatch, for the remaining purposes of this paper, we will hereafter simply use the term bycatch for discard mortality from non-directed fisheries. Bycatch represents all discarded fish estimated to have died due to capture; the discard mortality rates vary over time and by fishery, ranging from single percentages in some line fisheries to 100% in other fisheries. Bycatch represents a substantial source of mortality, and it is estimated to be 6.06 million pounds, ~2750 t, or 16% of the total mortality from all sources in 2018.

Topic 1: The current stock assessment explicitly includes all bycatch mortality (both fish less than 26", U26, and fish larger than 26", O26) in the same manner the mortality from recreational, subsistence, and commercial sources are also included. The effects of bycatch on the stock dynamics, including projections, is informed via the conversion of length-frequency data from all sampled bycatch fisheries weighted by the mortality from each fishery, and converted to age-data via age-length keys. Bycatch mortality includes Pacific halibut from 2-15+ years old, with the largest mortality between age-3 and age-8.

Topic 2: The IPHC's interim management procedure accounts for all O26 bycatch directly in the TCEY (or 'distributed mortality', which includes all mortality except the U26 bycatch) for each IPHC Regulatory Area. U26 bycatch is included, via the stock assessment, in the calculation of coastwide Spawning Potential Ratio (SPR; a measure of fishing intensity that includes the lifetime contribution per recruit to the spawning biomass). This approach is in contrast to some historical Pacific halibut analyses which did not account for the mortality of U26 Pacific halibut in any way. Including U26 bycatch mortality in the SPR calculation, but not by individual IPHC Regulatory Area allows for movement of these fish prior to entry in most of the directed fisheries, and implicitly assumes that they would have been distributed in proportion to the biomass distribution described

by the modelled survey results each year. While reasonable for short-term analysis, this assumption does not include the long-term effects of age-specific mortality on subsequent distribution.

Topic 3: Comparing the projected 2019 mortality associated with the IPHC's Interim Management Procedure with two alternative levels of projected bycatch mortality (no bycatch, and no U26 bycatch) allows for the evaluation of the effects of bycatch mortality on 2019 directed fishery yield. These comparisons were performed by holding the SPR constant at the reference level ($F_{46\%}$; the level of fishing intensity estimated to reduce the female spawning biomass per recruit to 46% of its unfished equilibrium).

Coastwide results showed an increase in the coastwide TCEY of 3.66 million pounds (~1660 t), or a rate of 0.6 lbs of additional TCEY for every pound of bycatch reduced. This increase in the coastwide TCEY is due to the fish directly 'gained' by eliminating the U26 mortality, and the change in the effect on the stock of replacing O26 bycatch (focused on younger fish, both O26 and U26) with directed fisheries (selecting older fish). Because the O26 portion of the bycatch is included in the TCEY, the absolute increase in yield to the directed fisheries was 7.99 million pounds (~3620 t; 4.33 million pounds of reduced O26 bycatch plus the additional 3.66 million pounds). When only the U26 bycatch (1.73 million pounds; ~ 780 t) was removed from the projections, the TCEY increased by 3.24 million pounds (~1470 t), or a rate of 1.87 lbs of additional TCEY for every pound of U26 bycatch reduced. This estimated rate reflects the additional lifetime contribution expected from U26 bycatch (primarily less than six years old) relative to that of older fish.

Regulatory Area results by individual IPHC Regulatory Area are also provided, as are increases to the FCEY (a metric that depends on the catch agreement in place in each IPHC Regulatory Area, but always includes at least the directed commercial fishery), and rates of increase of FCEY are also reported (Table 2).

These results depend on the current biology of the stock (maturity schedule, weight-at-age, and year-class structure), the dynamics of the current fishery (the relative selectivity of each fishery sector, and the catch agreements allocating mortality among sectors), and the Interim Management Procedure (the target SPR and the procedure for distributing mortality among individual IPHC Regulatory Areas). For these reasons, consideration of the TCEY increase rate is only relevant to current management; it does not represent a static 'exchange rate' but would need to be recalculated for future evaluation. Preliminary investigation of this topic using the Management Strategy Evaluation (MSE) operating model suggests that this range of variability will be very broad under a wide range of stock, fishery, and management procedure conditions. Distributional 'feedback' effects of mortality on younger halibut, which have the potential to migrate extensively before contributing to the directed fisheries, can only be investigated through a spatially explicit modelling framework. Efforts underway in the Management Strategy Evaluation process will likely provide the best avenue for such investigation over the next several years.

Methods

Topics 1 and 2 are described below, consistent with previously published IPHC documents.

Topic 3 is evaluated using the 2018 stock assessment ensemble stock assessment. Three cases are presented:

a) The projection of the Interim Management Procedure for 2019 as is currently available via the IPHC's mortality projection tool. The Interim Management Procedure consists of a target coastwide SPR of 46%, and a TCEY distribution based on the O32 modelled survey stock distribution and the relative harvest rates of 1.0 for IPHC Regulatory Areas 2A-3A and 0.75 for IPHC Regulatory Areas 3B-4CDE.
b) All U26 bycatch (in all IPHC Regulatory Areas) is removed from the projection for 2019 by reducing the input bycatch mortality and fixing the bycatch selectivity curve applied in the projection to exclude the relevant ages (approximated by ages 2-5). The remaining fisheries are then increased proportionally to achieve the target fishing intensity ($F_{46\%}$) consistent with the Interim Management Procedure.
c) All bycatch mortality (in all IPHC Regulatory Areas) is removed from the projection for 2019. The remaining fisheries are then increased proportionally to achieve the target fishing intensity ($F_{46\%}$) consistent with the Interim Management Procedure.

The results of the three cases are compared in order to evaluate the magnitude of difference between the FCEYs and TCEYs for each case (both coastwide and by IPHC Regulatory Area) as well as the increase rates, or gains in yield achieved through reduced bycatch.

Results

Topic 1: Bycatch in the stock assessment

The current stock assessment explicitly includes all bycatch mortality in the same manner that mortality from recreational, subsistence, and commercial sources are included. The magnitude of Pacific halibut bycatch is reported to the IPHC each year by NOAA-Fisheries (National Marine Fisheries Service, NMFS; for Alaska and Washington-Oregon-California) and Fisheries and Oceans Canada (DFO; for British Columbia). For fisheries still operating at the time the data sources for the annual stock assessment are finalized each year (approximately the end of October) mortality is extrapolated through the end of the calendar year. For 2018, bycatch was estimated to be 6.06 million pounds (~2750 t), or 16% of the total mortality from all sources (Table 1).

The length-distribution of Pacific halibut caught as bycatch in fisheries targeting other species is also reported to the IPHC each year by the NMFS and DFO. These estimates are based on at-sea observer programs, and are only available through the previous year (i.e. 2017 bycatch lengths were available for the 2018 stock assessment and were used as a proxy for 2018 as well as for 2017). The historical time-series of these lengths is summarized each year by IPHC Regulatory Area, and also aggregated to the coastwide level (weighting by the total estimated number of Pacific halibut represented in the bycatch mortality). In order to evaluate these length data directly in the context of the age-structured stock assessment, they are converted to age-distributions. Due to the large frequency of very small (and young) Pacific halibut observed in the bycatch, the length-to-age relationships from neither the setline survey, nor the directed halibut fishery are applicable. Pacific halibut of all ages are routinely sampled for length and age by IPHC samplers on the NMFS trawl surveys conducted in the Bering Sea, Gulf of Alaska, and Aleutian Islands. These data contain Pacific halibut of roughly the same size-range as are observed in the bycatch data. Annual age-length keys are produced from the NMFS survey data for each year. Relatively few fish greater than age-15 were present in these data; therefore, to avoid extensive smoothing or extrapolation across years, the keys are aggregated at age-15. These annual age-length keys are used to convert the coastwide aggregate bycatch length frequency estimates into predicted ages. Bycatch mortality includes Pacific halibut from 2-15+ years old, with the largest components of the mortality represented by age-3 through approximately age-8 (Figure 1).

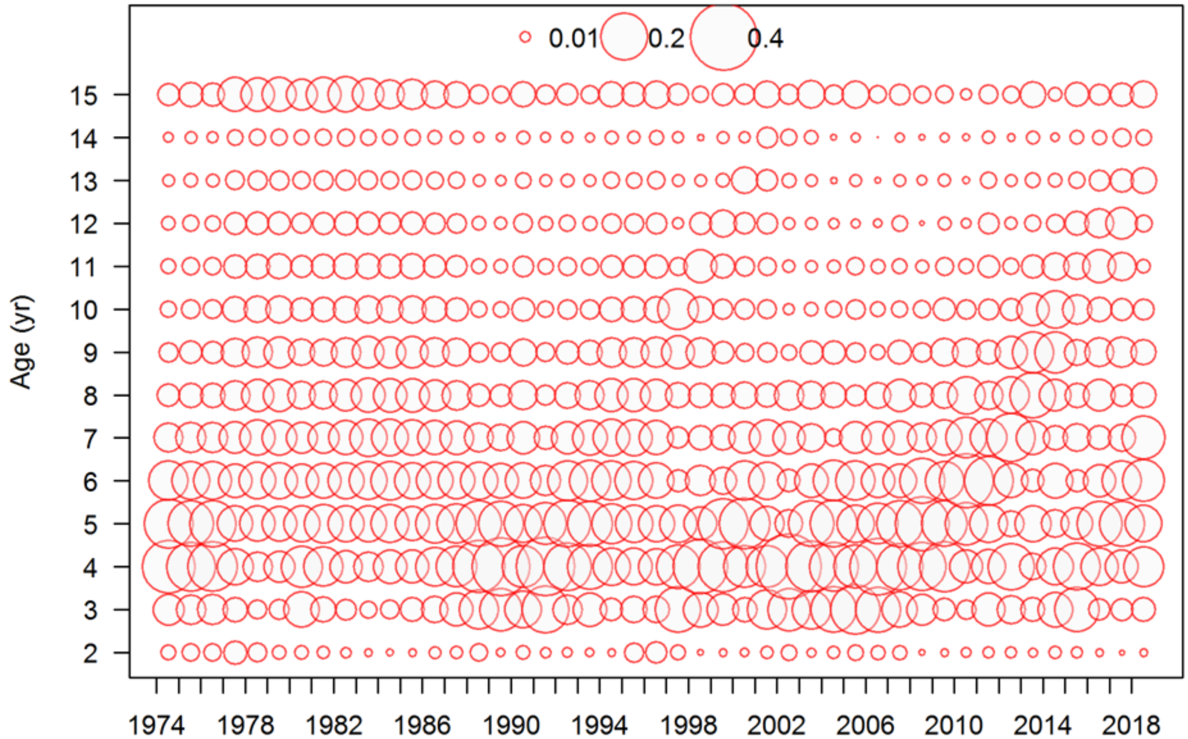

FIGURE 1. Estimated age frequencies of bycatch mortality 1974-2018. Area of the circles is proportional to the estimated bycatch (in numbers) for each age in each year.

TABLE 1. Estimates of bycatch in 2018.

Bycatch (Mlb)		2A	2B	2C	3A	3B	4A	4B	4CDE	Region 2	Region 3	Region 4	Region 4B	Total
U26		0.00	0.02	0.00	0.37	0.11	0.10	0.01	1.12	0.02	0.48	1.22	0.01	1.73
	Percent	0.1%	1.2%	0.0%	21.5%	6.3%	5.6%	0.5%	64.8%	1.3%	27.8%	70.4%	0.5%	100%
O26		0.13	0.27	0.03	1.28	0.36	0.18	0.22	1.87	0.43	1.64	2.05	0.22	4.33
	Percent	3.0%	6.2%	0.7%	29.6%	8.2%	4.1%	5.0%	43.1%	9.9%	37.8%	47.3%	5.0%	100%
Total		0.13	0.29	0.03	1.65	0.46	0.28	0.23	2.99	0.45	2.12	3.26	0.23	6.06
	Percent	2.1%	4.8%	0.5%	27.3%	7.6%	4.5%	3.7%	49.3%	7.5%	34.9%	53.8%	3.7%	100%

Coastwide bycatch in the stock assessment model is treated as a single 'fishery' with selectivity estimated via the fit to the age-frequency information. Due to uncertainty in the reliability of some historical bycatch length-frequency information, these data are 'downweighted' in the assessment models such that selectivity is estimated, but information on year-class strength is not imparted to the analysis. Ongoing efforts by the IPHC to reconcile historical bycatch estimates and biological data may be able to provide a more reliable time-series for future stock assessments. Selectivity of the coastwide bycatch 'fishery' is estimated to be domed, consistent with the age data suggesting proportionally fewer older Pacific halibut represented in the bycatch than in the directed fisheries and in the population.

Topic 2: Bycatch in the Interim Management Procedure

The IPHC's Interim Management Procedure has changed appreciably since 2012. In that year, the IPHC began to transparently delineate between the results of scientific analyses, the application of harvest policy, and the management decisions resulting in annual mortality limits. From 2012 through 2017, the 'Blue Line' represented the results of both the scale and distributional targets of the IPHC's harvest policy, although it was never applied to annual catch limits (based on FCEYs) at the coastwide level or as a complete set of Regulatory Area-specific limits. In 2017, the Commission adopted a 'Reference' level of coastwide fishing intensity based on the average of values estimated (from the 2016 stock assessment) for the period from 2014 through 2016. This reference was an SPR of 46%. In addition, the Commission directed the Secretariat to provide for future management decisions to be based on TCEYs, rather than FCEYs, such that catch limits would be more comparable across Regulatory Areas. The SPR target provides the coastwide scale of fishing intensity for the Interim Management Procedure, which determines the coastwide TCEY.

There are two inputs to the Interim Management Procedure for distributing the coastwide TCEY among IPHC Regulatory Areas: the current biological stock distribution, and the relative target harvest rates. The stock distribution has historically been based on the modelled survey estimates (IPHC's Fishery Independent Setline Survey, FISS, and other survey sources integrated via the IPHC's space-time model) of O32 Pacific halibut (greater than 32" in length). Although the FISS could provide a biological stock distribution estimate based on the modelled estimates of all sizes of Pacific halibut caught in the setline survey which would be more consistent with the delineation of U26 and O26 Pacific halibut mortality, this has not been the method for historical analyses, and the O32 distribution is retained for consistency. The relative target harvest rates for each IPHC Regulatory Area are 1.00 for Areas 2A-3A, and 0.75 for Areas 3B-4CDE, and are consistent with the historical rates of 21.5% and 16.125% (the ratio being equal to 1.00:0.75) used prior to the transition to an SPR-based fishing intensity target. The combination of the stock distribution and relative target harvest rates results in a target distribution for the annual TCEY.

The IPHC's Interim Management Procedure delineates between O26 and U26 Pacific halibut, and this information comes from the length data. The length-weight relationship is applied to the length frequency distributions by individual IPHC Regulatory Area in order to estimate the fraction of the mortality (in pounds) represented by U26 and O26 fish. These fractions are then applied to the reported totals to produce mortality estimates partitioned into U26 and O26 components. In 2018, an estimated 29% of the bycatch was estimated to be U26 and 61% O26 across the entire coast (Table 1). The Interim Management Procedure accounts for all O26 bycatch directly in the TCEY for each IPHC Regulatory Area. The U26 mortality is included in the stock assessment (as described above) and reported in the detailed mortality tables produced by the IPHC's mortality projection tool (https://iphc.int/data/projection-tool), but is not deducted from the individual Regulatory Area's TCEY. This approach is in contrast to some historical Pacific halibut analyses which did not report or account for the mortality of U26 Pacific halibut in any way.

To apply the Interim Management Procedure (both scale and distribution), the stock assessment is applied iteratively via the following method:

1) Adding the projected mortality for 2019 to each of the four stock assessment models comprising the ensemble
2) Calculating the projected SPR for each model
3) Integrating the model results into a probability distribution for the projected SPR
4) Comparing the median projected SPR to the reference level (46%)
5) Scaling the TCEY and repeating this process starting from 1) until the median result is equal to the reference.

Topic 3: Effects of bycatch on projected 2019 yield

The projected 2019 mortality associated with the IPHC's Interim Management Procedure is set as the default inputs in the IPHC's mortality projection tool (https://iphc.int/data/projection-tool). The FCEYs and TCEYs that result from that projection are summarized in the upper section of Table 2. Those results can be compared to the two alternative projections: one with no bycatch mortality, and a second with no U26 bycatch mortality, both maintain the same scale of fishing intensity ($F_{46\%}$) and the same distribution (i.e., proportion) of TCEY among individual Regulatory Areas (as described above). There are two important aspects of each set of results: 1) how much TCEY was shifted from bycatch to directed fisheries, and 2) how much additional TCEY was created by the change in the effect on the stock of replacing bycatch (focused on younger fish) with directed fisheries (selecting older fish).

For the projection with no bycatch in 2019 (Table 2; center section), results showed an increase in the coastwide TCEY of 3.66 million pounds (~1660 t), or a rate of 0.6 lbs of additional TCEY for every pound of bycatch reduced. This increase in the coastwide TCEY is due to the fish directly 'gained' by eliminating the U26 mortality, and the change in the effect on the stock of replacing O26 bycatch (focused on younger fish) with directed fisheries (selecting older fish). Because the O26 portion of the bycatch is included in the TCEY, the absolute increase in yield to the directed fisheries was 7.99 million pounds (~3620 t; 4.33 million pounds of reduced O26 bycatch plus the additional 3.66 million pounds). Results show a 9.2% increase in TCEY in all IPHC Regulatory Areas (by definition, as the TCEY distribution in the Interim Management procedure remains constant); however, increases to the FCEY (a metric that depends on the catch agreement in place in each IPHC Regulatory Area, but always includes at least the directed commercial fishery) vary substantially among IPHC Regulatory Areas. Differences in the FCEY range from 13.7% in IPHC Regulatory Area 2C, where there is very little bycatch, to 85.8% in IPHC Regulatory Area 4CDE where bycatch is much larger than the FCEY. The breakdown to individual fishery sectors within the FCEY can be evaluated further via the IPHC's mortality projection tool (https://iphc.int/data/projection-tool) for any FCEY and IPHC Regulatory Area combination.

For the projection with no U26 bycatch (Table 2; lower section) there was an increase in the TCEY of 3.24 million pounds (~1470 t), or 8.1% distributed across each individual IPHC Regulatory Area TCEY. The amount of U26 bycatch removed from the projection was 1.73 million pounds (~ 780 t), and since none of this was included in the TCEY, the rate of TCEY increase reflects the entire increase, corresponding to a rate of 1.87 lbs of additional TCEY for every pound of U26 bycatch reduced. This estimated rate is much higher than that for the projection removing all bycatch, as it reflects the additional lifetime contribution expected from U26 bycatch (primarily less than six years old) relative to that of older fish. Results by individual IPHC Regulatory Area FCEY vary much less than the alternative removing all bycatch, and only in response to differences in the catch agreements.

Discussion

These results depend on the current biology of the stock. The specific biological factors that contribute to the calculation of SPR include:

- The maturity schedule,
- The observed weight-at-age,
- The year-class structure in the current population (because it interacts with selectivity to produce the equilibrium spawning biomass with fishing)

The calculation of SPR relies on the specific dynamics of the current fishery including the relative selectivity of each fishery sector which is modelled with separate selectivity relationships for directed commercial (by Biological Region in the Areas-As-Fleets model assessment models), commercial discard mortality, recreational and subsistence and bycatch. Further, the catch agreements allocating mortality among sectors also influence the effect of mortality on the population and are therefore important to the calculation of SPR. Finally, the sources of fishery mortality are operating on the modelled stock simultaneously, which means that the target level of fishing intensity will effect the relative importance of each fishery sector. Specifically, a very high exploitation rate would truncate the age structure of the modelled population and serve to dampen the difference between mortality from one source to another. Similarly, the procedure for distributing mortality among individual IPHC Regulatory Areas influences the effects of mortality across the entire stock, as each IPHC Regulatory Area has a differing mix of fisheries (and selectivity schedules) comprising the TCEY. For all of the above reasons, this analysis for consideration of the effects of bycatch, and particularly the TCEY increase rate is only relevant to current management; the results *do not* represent a static ‘exchange rate’ but would need to be recalculated for future evaluation. Preliminary investigation of the effects of bycatch across a wide range of population and fishery conditions using the MSE operating model suggests that the results may vary considerably.

TABLE 2. Comparison among 2019 FCEYs and TCEYs from the IPHC's Interim Management Procedure (IMP), a projection of no bycatch, and a projection of no U26 bycatch.

Interim Management Procedure (IMP)	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4CDE**	**Region 2**	**Region 3**	**Region 4**	**Region 4B**	**Total**
FCEY	0.64	4.09	4.42	13.10	2.39	1.91	1.70	2.62	9.14	15.50	4.52	1.70	30.86
TCEY	0.78	4.91	6.26	16.35	2.97	2.21	1.95	4.59	11.95	19.31	6.80	1.95	40.00
No Bycatch (-6.06 Mlb)	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4CDE**	**Region 2**	**Region 3**	**Region 4**	**Region 4B**	**Total**
FCEY	0.83	4.78	5.02	15.88	2.97	2.27	2.09	4.86	10.64	18.85	7.13	2.09	38.71
Difference from IMP	0.20	0.69	0.61	2.78	0.58	0.36	0.39	2.24	1.50	3.36	2.61	0.39	7.85
Percent difference	30.7%	17.0%	13.7%	21.2%	24.1%	19.0%	22.9%	85.8%	16.4%	21.7%	57.6%	22.9%	25.4%
								2019 FCEY increase rate (lbs FCEY/lbs bycatch)					1.29
TCEY	0.85	5.36	6.83	17.84	3.24	2.41	2.13	5.01	13.04	21.08	7.42	2.13	43.66
Difference from IMP	0.07	0.45	0.57	1.50	0.27	0.20	0.18	0.42	1.09	1.77	0.62	0.18	3.66
Percent difference	9.2%	9.2%	9.2%	9.2%	9.2%	9.2%	9.2%	9.2%	9.2%	9.2%	9.2%	9.2%	9.2%
								2019 TCEY increase rate (lbs TCEY/lbs bycatch)					0.60
No U26 Bycatch (-1.73 Mlb)	**2A**	**2B**	**2C**	**3A**	**3B**	**4A**	**4B**	**4CDE**	**Region 2**	**Region 3**	**Region 4**	**Region 4B**	**Total**
FCEY	0.70	4.47	4.92	14.43	2.62	2.08	1.85	2.98	10.10	17.04	5.06	1.85	34.05
Difference from IMP	0.06	0.38	0.51	1.32	0.22	0.17	0.15	0.36	0.95	1.55	0.53	0.15	3.19
Percent difference	9.7%	9.4%	11.5%	10.1%	9.3%	8.9%	9.1%	13.9%	10.4%	10.0%	11.8%	9.1%	10.3%
								2019 FCEY increase rate (lbs FCEY/lbs U26 bycatch)					1.84
TCEY	0.84	5.31	6.77	17.67	3.21	2.39	2.10	4.96	12.91	20.87	7.35	2.10	43.24
Difference from IMP	0.06	0.40	0.51	1.32	0.24	0.18	0.16	0.37	0.97	1.56	0.55	0.16	3.24
Percent difference	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%	8.1%
								2019 TCEY increase rate (lbs TCEY/lbs U26 bycatch)					1.87

Including U26 bycatch mortality in the SPR calculation, but not by individual IPHC Regulatory Area allows for movement of these fish prior to entry in most of the directed fisheries, and implicitly assumes that they would have been distributed in proportion to the biomass distribution described by the modelled survey results each year. While reasonable for short-term analysis, this assumption does not include the long-term effects of age-specific mortality interacting with movement rates to effect subsequent stock distribution. The distributional 'feedback' effects of mortality on younger Pacific halibut is an important component in exploring the effects of bycatch mortality. These effects can only be investigated through a spatially explicit modelling framework that accounts for movement rates. Efforts underway in the MSE process will likely provide the best avenue for such an analysis over the next several years. The MSE approach will also allow for evaluation of the additional feedback created over time if the magnitude of bycatch changes with stock abundance, and through the use of alternative management procedures that may utilize target fishing intensities, harvest control rules or other mechanisms that effect the long-term yield available from the Pacific halibut population.