# Analysis of the effects of historical discard mortality in non-directed fisheries ('bycatch')

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## PURPOSE

To provide the Commission with a response to the Commission's request:

> "*AM095–Rec.05 (para. 67) The Commission **RECOMMENDED** that the IPHC Secretariat expand upon the analysis completed in IPHC-2019-AM095-INF08 "Treatment and effects of Pacific halibut discard mortality (bycatch) in non-directed fisheries projected for 2019", to be reviewed by the SRB at its next meeting. The objective of this work is to estimate lost yield from bycatch of Pacific halibut in non-directed fisheries for the years of 1991-2018.*"

## INTRODUCTION

There has been a long-standing interest in understanding the trade-off between yield in the directed Pacific halibut fisheries, stock or spawning biomass and mortality of Pacific halibut due to discards in non-directed fisheries ('bycatch'). Summary and analysis historically focused on accounting for 'lost' spawning output (Salveson et al. 1992) as well as direct estimates of 'yield loss' including both immediate and delayed effects throughout the potential life-span of a fish experiencing this mortality (Adlerstein 1993; Adlerstein 1994). Yield loss has been defined differently among studies, but all included at least the directed commercial fishery landings. Yield loss was generally found to be very sensitive to the specific non-directed fleet being investigated, as well as the year, location and season of the comparison. Specific gear by area and season components ranged from values less than 1.0 to as high as 3.3 pounds of yield gained in the directed commercial fishery per pound of discard mortality in non-directed fisheries (Adlerstein 1993; Adlerstein 1994). An early estimate of aggregate yield loss including all non-directed fisheries indicated a rate of 1.7 pounds per pound (Sullivan et al. 1994). Another analysis indicated lower values around 1.12 (for 1995 specifically; calculated from the results in Clark and Hare 1998). Clark and Hare (1998) also attempted to estimate the distribution of the yield loss under varying hypotheses regarding movement rates. They found that much of the lost yield was estimated to occur in the IPHC Regulatory Area in which the mortality from non-directed fisheries had been realized. Hare and Clark (2007) reported historical yield loss values of 1.40 and 1.58 from the early and late 1980s respectively. More recently, yield loss was estimated to be 1.14 (Hare and Williams 2013).

Many of the early analyses made simple assumptions regarding the selectivity of both the mortality in non-directed fisheries and in the directed commercial Pacific halibut fishery. Specifically these models often did not explicitly include dynamics for fish less than 6 or 8 years of age, and did not always account for sub-legal mortality (fish below the current 32 inch (82 cm) minimum size limit). The trade-off between yield and economic value in the directed fisheries and discard mortality in non-directed fisheries has been found to be quite sensitive to the discard mortality rates in the directed fisheries (Martell et al. 2015).

In 2018, the IPHC Secretariat evaluated alternative projections for 2019-21 under alternative scenarios of no discard mortality in non-directed fisheries (bycatch) and no discard mortality in non-directed fisheries for Pacific halibut less than 26 inches (66 cm) in length (U26; IPHC-2019-AM095-INF07, IPHC-2019-AM095-INF08). That analysis rephrased the metric for comparison as potential 'yield gain', as the focus was to describe the change in the directed fisheries (a 'gain') as mortality in non-directed fisheries was reduced; however, even though the term has changed, the values can be interpreted in the same manner as estimates from historical analysis. The results indicated that over short-term projections (2019-2021) the current Catch Sharing Plans (CSPs), selectivity and biology (weight-at-age) led to a potential yield gain of 1.25-1.29 pounds of FCEY yield for every pound of discard mortality in non-directed fisheries (bycatch) removed from the projections. The methods used to create these estimates were based on maintaining a constant Spawning Potential Ratio (SPR; Goodyear 1993) while shifting yield from non-directed fisheries mortality to the directed fisheries. That approach is consistent with the concept of the 'fisheries footprint' introduced in 2016 (Martell et al. 2016). Briefly, the fisheries footprint accounts for the simultaneous nature of multiple sources of mortality to describe the relative contribution of each to the SPR of the population. This type of approach is necessary where fishing and natural mortality is simultaneous rather than sequential (e.g. 'adult equivalents' used for Pacific salmon analyses) because some of the fish that survive one source succumb to another prior to contribution to the long-term spawning output of the population.

## METHODS

This analysis used the preliminary 2019 stock assessment (four models; IPHC-2019-SRB014-07) to evaluate the hypothetical yield gained by the directed Pacific halibut fisheries in the absence of annual historical discard mortality in non-directed fisheries (bycatch). Although the Commission request specified a starting year of 1991, current short time-series stock assessment models (two of the four) extend only as far back as 1992, so the analysis includes only 1992-2018.

The methods follow the conceptual approach that produced the 2018 analysis (IPHC-2019-AM095-INF07, IPHC-2019-AM095-INF08). This approach is purely numerical (iteratively solving for the solution) in order to most accurately represent the conditions estimated in the stock assessment for each year. It differs importantly in application from the analysis performed in 2018 in that this analysis is retrospective (rather than a projection), which requires a slightly different set of procedures to maintain consistency with assessment results (described below).

The steps to conduct this analysis were as follows:

a) Set all model parameters in each of the four stock assessment models to initialize at the maximum likelihood estimates from the preliminary 2019 stock assessment.
b) Set stock synthesis (the software used to implement the individual stock assessment models) input controls to calculate the time-series of population and fishery quantities without solving for new parameter values (maximum phase = 0; Methot et al. 2019).
c) For the target year (each year from 1992 through 2018 was analyzed independently), set discard mortality from non-directed fisheries (bycatch) equal to a value of zero.
d) Increase the directed commercial fishery mortality in the target year (including both landings and discard mortality) by a scaling factor, α (an arbitrary starting point of 1.0 was used for the first target year analyzed, subsequent years used the previous target year's starting point to speed convergence).
e) Recalculate the time-series of population and fishery quantities for each model.
f) Because the variance for the estimate SPR from each model is not available (the parameters are not re-estimated), the original variance from each of the preliminary 2019 stock assessment models was used to integrate the results of the four models and to calculate the median ensemble SPR for that year.
g) Compare the median ensemble SPR for the target year to the original estimate from the preliminary 2019 stock assessment. If it does not match (to the third decimal place), repeat steps d-f by adjusting α up or down accordingly.

h) Calculate the difference between the directed commercial fishery mortality after step g and the original directed commercial fishery mortality to determine the raw potential yield gained.

The raw potential yield gained was then divided by the discard mortality in non-directed fisheries that had been removed in order to determine the potential yield gain rate. In order to evaluate the hypothetical spatial distribution of yield gained by the directed Pacific halibut fisheries, basic properties of the IPHC's interim management strategy were applied as a simple approximation to historical decision-making. These properties included:

1) All discard mortality in non-directed fisheries (bycatch) of Pacific halibut greater than 26 inches (66 cm) in length (O26) was transferred to the directed commercial fishery within the IPHC Regulatory Area in which it occurred. This step is consistent with the IPHC's interim management strategy of directly transferring O26 non-directed fishery discard mortality to the directed fisheries based on projected levels.
2) The directed commercial fishery in all IPHC Regulatory Areas were then scaled up or down in proportion to the distribution of the directed commercial fishery mortality across IPHC Regulatory Areas in that year to match the overall hypothetical yield gain. This step implicitly assumes that the decision making leading to the distribution of mortality for the directed commercial fishery would have been maintained and applied to the additional (or reduced) hypothetical yield available in each year.

As a secondary analysis, a more general comparison was made using tools created for evaluation of reference points for the ongoing Management Strategy Evaluation. The underlying model and equations are documented in IPHC-2019-SRB015-11. Briefly, a simplified population dynamics model was created with options to partition fishing mortality (*F*) between a directed Pacific halibut fleet (not including discard mortality) and a fleet representing discard mortality in non-directed fisheries. The population and fleet dynamics (selectivity) parameters were based on relatively recent (2018) estimates from the stock assessment (IPHC-2019-AM095-09). A specific case of the general reference point evaluation was created to provide some comparability with the methods described above. Importantly, SPR was held constant at a value of 0.46, weight-at-age was set to resemble recent conditions (low weight-at-age scenario), and a comparison was made between the aggregate yield estimated for four scenarios: 1) 100% directed fishery, 2) 80% directed and 20% non-directed discard mortality, 3) 40% directed and 60% non-directed discard mortality, and 4) 100% non-directed discard mortality.

## RESULTS

Historical discard mortality in non-directed fisheries (bycatch) has decreased almost monotonically from a high of just over 20 million pounds in 1992 to a low of 6.06 million pounds in 2018 (Table 1). This decrease was concurrent, but not in exact proportion to decreases in the estimated spawning biomass of Pacific halibut over much of this time-period (IPHC-2019-SRB014-07). The effects of discard mortality in non-directed fisheries on hypothetical yield to directed commercial Pacific halibut fishery have differed over time (Figure 1, Table 2). Specifically, during the mid-1990s, a period of very abundant young Pacific halibut and a relatively low level of fishing intensity (IPHC-2019-SRB014-07) moving yield from non-directed fisheries to the directed commercial fishery is estimated to have a larger effect on the stock (and thus a yield gain rate < 100%) as measured via SPR. In later years and over most of the time series the hypothetical yield gain rate was estimated to be larger than 100%, ranging up to 139% in 2010 (Table 2) and averaging 115% over the entire time-series.

Based on the distribution of O26 non-directed fishery discard mortality and the actual distribution of commercial fishery catch (both landings and estimated discard mortality), the hypothetical yield gain is distributed differently in each year as both sources changed over time (Table 3). Although similar to the spatial distribution of discard mortality in non-target fisheries, the aggregate yield gain over the entire time-series is greater than the observed mortality in IPHC Regulatory Areas 2B-3B and smaller than the observed mortality in IPHC Regulatory Areas 4A-4CDE (Table 4).

**TABLE 1**. Discard mortality in non-directed fisheries (bycatch) of all sizes 1992-2018 (million net pounds).

| Year | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1992 | 0.44 | 1.75 | 0.74 | 4.67 | 1.98 | 2.49 | 1.17 | 7.06 | 20.29 |
| 1993 | 0.44 | 1.66 | 0.74 | 4.29 | 1.06 | 1.80 | 0.85 | 5.11 | 15.96 |
| 1994 | 0.44 | 1.22 | 0.53 | 3.91 | 1.39 | 2.20 | 1.04 | 6.24 | 16.95 |
| 1995 | 0.61 | 1.52 | 0.35 | 2.96 | 1.76 | 2.02 | 0.96 | 5.75 | 15.93 |
| 1996 | 0.61 | 0.30 | 0.35 | 2.74 | 1.96 | 1.97 | 0.93 | 5.60 | 14.46 |
| 1997 | 0.61 | 0.22 | 0.40 | 2.97 | 1.44 | 1.83 | 0.86 | 5.19 | 13.51 |
| 1998 | 1.08 | 0.21 | 0.09 | 2.66 | 1.39 | 1.79 | 0.85 | 5.09 | 13.16 |
| 1999 | 0.99 | 0.19 | 0.06 | 2.89 | 1.74 | 1.78 | 0.84 | 5.06 | 13.54 |
| 2000 | 0.82 | 0.23 | 0.13 | 2.89 | 1.51 | 1.73 | 0.81 | 4.90 | 13.02 |
| 2001 | 0.84 | 0.18 | 0.06 | 3.01 | 1.68 | 1.65 | 0.78 | 4.69 | 12.88 |
| 2002 | 0.64 | 0.24 | 0.06 | 1.95 | 1.92 | 1.69 | 0.80 | 4.79 | 12.09 |
| 2003 | 0.26 | 0.24 | 0.07 | 2.94 | 1.73 | 1.58 | 0.75 | 4.49 | 12.07 |
| 2004 | 0.29 | 0.25 | 0.07 | 3.43 | 1.27 | 1.56 | 0.74 | 4.44 | 12.05 |
| 2005 | 0.54 | 0.35 | 0.05 | 2.98 | 1.13 | 1.78 | 0.84 | 5.07 | 12.74 |
| 2006 | 0.58 | 0.29 | 0.05 | 2.73 | 1.35 | 1.74 | 0.82 | 4.94 | 12.50 |
| 2007 | 0.39 | 0.32 | 0.06 | 2.60 | 1.07 | 1.59 | 0.48 | 4.81 | 11.31 |
| 2008 | 0.43 | 0.14 | 0.06 | 2.82 | 1.30 | 1.23 | 0.36 | 4.51 | 10.86 |
| 2009 | 0.51 | 0.21 | 0.05 | 2.48 | 1.25 | 1.56 | 0.46 | 4.02 | 10.54 |
| 2010 | 0.35 | 0.18 | 0.06 | 2.30 | 1.10 | 1.06 | 0.48 | 4.18 | 9.70 |
| 2011 | 0.09 | 0.23 | 0.05 | 2.49 | 1.12 | 0.97 | 0.48 | 3.02 | 8.45 |
| 2012 | 0.12 | 0.19 | 0.04 | 1.72 | 1.14 | 1.47 | 0.26 | 4.26 | 9.20 |
| 2013 | 0.07 | 0.23 | 0.03 | 1.63 | 0.89 | 0.87 | 0.14 | 4.98 | 8.83 |
| 2014 | 0.10 | 0.25 | 0.02 | 1.89 | 0.97 | 0.81 | 0.13 | 4.77 | 8.93 |
| 2015 | 0.08 | 0.33 | 0.02 | 2.10 | 0.66 | 0.64 | 0.22 | 3.43 | 7.47 |
| 2016 | 0.10 | 0.27 | 0.03 | 1.79 | 0.87 | 0.57 | 0.14 | 3.25 | 7.02 |
| 2017 | 0.13 | 0.25 | 0.02 | 1.43 | 0.89 | 0.40 | 0.21 | 2.75 | 6.07 |
| 2018 | 0.13 | 0.29 | 0.03 | 1.65 | 0.46 | 0.28 | 0.23 | 2.99 | 6.06 |

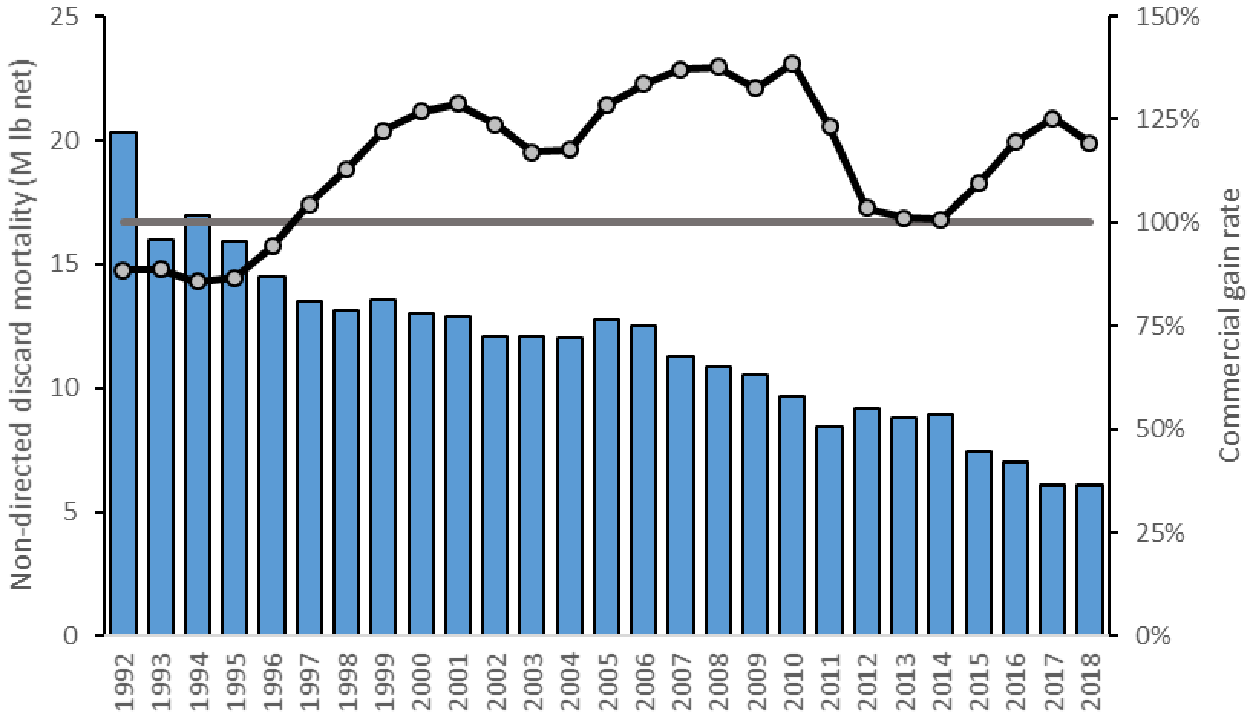


**FIGURE 1**. Summary of annual discard mortality in non-directed fisheries (bycatch; millions net pounds; bars) and hypothetical yield gain rate (yield gained per weight of discard mortality in non-directed fisheries removed; connected points) to directed commercial in the absence of annual discard mortality in non-directed fisheries. Horizontal line indicates a gain rate of 100%, or exact equivalency in trading yield between sectors.

**TABLE 2**. Summary of annual discard mortality in non-directed fisheries (bycatch; millions net pounds) by size category and hypothetical yield gain to the directed commercial fishery *including discard mortality* (millions net pounds) in the absence of annual discard mortality in non-directed fisheries (bycatch). The rate represents the hypothetical yield gained per weight of discard mortality in non-directed fisheries (bycatch) removed.

| | Discard mortality from non-directed fisheries (bycatch) | | | Directed commercial fishery yield gain | |
|---|---|---|---|---|---|
| Year | O26 | U26 | Total | yield | rate |
| 1992 | 13.11 | 7.18 | 20.29 | 17.97 | 89% |
| 1993 | 9.20 | 6.76 | 15.96 | 14.17 | 89% |
| 1994 | 12.4 | 4.55 | 16.95 | 14.54 | 86% |
| 1995 | 11.78 | 4.16 | 15.93 | 13.80 | 87% |
| 1996 | 11.50 | 2.96 | 14.46 | 13.63 | 94% |
| 1997 | 10.85 | 2.66 | 13.51 | 14.13 | 105% |
| 1998 | 10.84 | 2.32 | 13.16 | 14.87 | 113% |
| 1999 | 10.33 | 3.21 | 13.54 | 16.56 | 122% |
| 2000 | 9.90 | 3.13 | 13.02 | 16.53 | 127% |
| 2001 | 10.04 | 2.83 | 12.88 | 16.58 | 129% |
| 2002 | 8.55 | 3.54 | 12.09 | 14.97 | 124% |
| 2003 | 8.18 | 3.89 | 12.07 | 14.14 | 117% |
| 2004 | 8.20 | 3.86 | 12.05 | 14.18 | 118% |
| 2005 | 8.65 | 4.09 | 12.74 | 16.36 | 128% |
| 2006 | 8.08 | 4.42 | 12.50 | 16.70 | 134% |
| 2007 | 7.28 | 4.03 | 11.31 | 15.52 | 137% |
| 2008 | 7.05 | 3.81 | 10.86 | 14.96 | 138% |
| 2009 | 6.87 | 3.67 | 10.54 | 13.97 | 133% |
| 2010 | 6.32 | 3.38 | 9.70 | 13.44 | 139% |
| 2011 | 5.49 | 2.96 | 8.45 | 10.41 | 123% |
| 2012 | 5.85 | 3.35 | 9.20 | 9.52 | 104% |
| 2013 | 5.80 | 3.03 | 8.83 | 8.93 | 101% |
| 2014 | 6.19 | 2.73 | 8.93 | 9.00 | 101% |
| 2015 | 4.89 | 2.58 | 7.47 | 8.18 | 109% |
| 2016 | 4.95 | 2.07 | 7.02 | 8.39 | 120% |
| 2017 | 4.34 | 1.73 | 6.07 | 7.61 | 125% |
| 2018 | 4.33 | 1.73 | 6.06 | 7.22 | 119% |

**TABLE 3**. Distribution of hypothetical yield gain (millions net pounds) to directed commercial fisheries in the absence of annual discard mortality in non-directed fisheries (bycatch).

| Year | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4CDE | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1992 | 0.48 | 2.09 | 1.41 | 5.82 | 2.28 | 1.21 | 1.29 | 3.39 | 17.97 |
| 1993 | 0.49 | 2.01 | 1.39 | 4.82 | 1.35 | 0.54 | 0.89 | 2.68 | 14.17 |
| 1994 | 0.44 | 1.40 | 0.84 | 4.16 | 1.33 | 1.46 | 1.04 | 3.86 | 14.54 |
| 1995 | 0.61 | 1.71 | 0.61 | 3.02 | 1.48 | 1.13 | 0.92 | 4.33 | 13.80 |
| 1996 | 0.64 | 0.63 | 0.65 | 2.95 | 1.69 | 1.40 | 0.98 | 4.68 | 13.63 |
| 1997 | 0.65 | 0.74 | 0.80 | 3.50 | 1.54 | 1.33 | 0.98 | 4.59 | 14.13 |
| 1998 | 1.15 | 0.86 | 0.59 | 3.64 | 1.76 | 1.61 | 0.95 | 4.31 | 14.87 |
| 1999 | 1.08 | 1.13 | 0.80 | 4.39 | 2.56 | 1.42 | 1.10 | 4.06 | 16.56 |
| 2000 | 0.92 | 1.15 | 0.84 | 4.21 | 2.67 | 1.60 | 1.23 | 3.91 | 16.53 |
| 2001 | 0.95 | 1.02 | 0.73 | 4.23 | 2.57 | 1.70 | 1.14 | 4.24 | 16.58 |
| 2002 | 0.65 | 1.17 | 0.71 | 3.30 | 2.72 | 1.25 | 1.12 | 4.07 | 14.97 |
| 2003 | 0.31 | 1.10 | 0.67 | 3.90 | 2.50 | 1.25 | 1.05 | 3.36 | 14.14 |
| 2004 | 0.33 | 1.14 | 0.81 | 4.46 | 2.06 | 1.13 | 0.96 | 3.30 | 14.18 |
| 2005 | 0.54 | 1.52 | 1.07 | 4.81 | 2.09 | 1.34 | 1.07 | 3.93 | 16.36 |
| 2006 | 0.60 | 1.68 | 1.26 | 4.87 | 2.29 | 1.48 | 0.82 | 3.71 | 16.70 |
| 2007 | 0.45 | 1.50 | 1.07 | 4.98 | 1.93 | 1.35 | 0.54 | 3.71 | 15.52 |
| 2008 | 0.53 | 1.09 | 0.82 | 4.99 | 2.35 | 1.15 | 0.50 | 3.54 | 14.96 |
| 2009 | 0.59 | 1.02 | 0.65 | 4.43 | 2.31 | 1.30 | 0.54 | 3.13 | 13.97 |
| 2010 | 0.43 | 1.04 | 0.63 | 4.31 | 2.19 | 0.97 | 0.61 | 3.28 | 13.44 |
| 2011 | 0.16 | 0.96 | 0.31 | 3.40 | 1.71 | 0.87 | 0.59 | 2.42 | 10.41 |
| 2012 | 0.18 | 0.75 | 0.30 | 2.40 | 1.39 | 1.07 | 0.36 | 3.08 | 9.53 |
| 2013 | 0.12 | 0.76 | 0.30 | 2.25 | 0.99 | 0.66 | 0.24 | 3.60 | 8.93 |
| 2014 | 0.16 | 0.79 | 0.34 | 2.14 | 1.06 | 0.71 | 0.23 | 3.57 | 9.00 |
| 2015 | 0.15 | 1.00 | 0.44 | 2.42 | 0.80 | 0.57 | 0.35 | 2.45 | 8.18 |
| 2016 | 0.19 | 0.98 | 0.49 | 2.29 | 0.81 | 0.61 | 0.28 | 2.75 | 8.39 |
| 2017 | 0.22 | 0.91 | 0.47 | 2.07 | 1.10 | 0.43 | 0.34 | 2.07 | 7.61 |
| 2018 | 0.21 | 0.86 | 0.40 | 2.19 | 0.67 | 0.33 | 0.35 | 2.21 | 7.22 |

**TABLE 4**. Distribution of aggregate total time-series discard mortality in non-directed fisheries (1992-2018; Table 1) and hypothetical yield gain in the directed commercial fishery (Table 3).

| | 2A | 2B | 2C | 3A | 3B | 4A | 4B | 4CDE |
|---|---|---|---|---|---|---|---|---|
| Non-directed discard mortality | 3.7% | 3.7% | 1.3% | 22.8% | 11.1% | 12.4% | 5.3% | 39.7% |
| Yield gain | 3.7% | 8.7% | 5.4% | 28.0% | 13.5% | 8.4% | 5.7% | 26.4% |

The auxiliary analysis based on the non-time series specific model built for evaluation of reference points for Pacific halibut produced similar results to those from the time-series. Specifically, yield gain rates under equilibrium conditions (conceptually equivalent to the average over a very long time series) were estimated to range from 121-144%, between an 80:20 partition of directed:non-directed fishing mortality and a 0:100 partition (Table 5).

**TABLE 5**. Distribution of hypothetical yield gain to directed commercial fisheries in the absence of annual discard mortality in non-directed fisheries (bycatch).

| Scenario | Directed fishery *F* | Non-directed *F* | Relative yield | Gain rate |
|---|---|---|---|---|
| 1 | 100% | 0% | 1.00 | -- |
| 2 | 80% | 20% | 0.83 | 121% |
| 3 | 40% | 60% | 0.73 | 137% |
| 4 | 0% | 100% | 0.69 | 144% |

## DISCUSSION

The yield gain rate between directed fisheries and non-directed fisheries depends on a large number of temporally varying biological factors including: the population age structure, the relative population biomass, the maturity schedule as well as the weight-at-age. In addition, fishery and management factors including the aggregate level of fishing intensity exerted on the stock (SPR), the selectivity specific to each of the directed and non-directed fisheries, and also the relative allocation among components within the directed (i.e., commercial, recreational, subsistence) and non-directed (trawl, pot, hook-and-line) fisheries. A change in any of these factors will lead to a change in the yield gain rate, as evidenced by the variability over time observed even in this simple analysis.

The individual models comprising the stock assessment do not currently allow for time-varying selectivity for discard mortality in non-target fisheries (bycatch; IPHC-2019-SRB014-07); doing so would affect the results. To the degree that the size and age structure of the discard mortality reflects that of the Pacific halibut population, time-varying selectivity may dampen the variability in yield gain rates, as the more abundant demographic components (with a reduced effect on SPR) would be more heavily selected.

This analysis does **not** represent a 'replay' of history with alternative management decisions. The SPR is held constant at the actual estimate from each year, therefore the approach uses the 'fishery footprint' concept to replace one source of mortality (discard mortality in non-directed fisheries; bycatch) with another (directed Pacific halibut fisheries). Because the relative 'footprint' of each source of mortality depends on the overall fishing intensity (SPR), the effects of discard mortality in non-directed fisheries (bycatch) would have differed under alternative harvest strategies. Further, such differences would compound over the time-series: differences from the actual history beginning in 1992 would have changed the stock and fishery interactions both in 1992 and in all subsequent years. Therefore, this analysis only represents one potential measurement tool with which to gauge the relationships between yields to the directed and non-directed Pacific halibut fisheries.

In aggregate, the results of this analysis are generally consistent with those from historical analyses and those based on alternative methods. Mortality reduced in non-directed fisheries, because it has a larger effect on smaller/younger Pacific halibut, generally corresponds to a larger yield in directed fisheries, in this case an average of 115% over the period 1992-2018. The spatial distribution of this hypothetical yield is largely reflective of the distribution of mortality in non-directed fisheries; however, the actual distribution of directed fishery mortality indicates that more of this hypothetical yield may have been taken historically in the eastern IPHC Regulatory Areas of the stock. The trade-off in yield among fisheries is only one part of the IPHC's long-term harvest strategy. Considering this topic in tandem with other management decisions may be best pursued through the ongoing Management Strategy Evaluation.

## RECOMMENDATION/S

That the Commission:

a) **NOTE** paper IPHC-2019-IM095-11 which provides an analysis of the effects of historical discard mortality in non-directed fisheries (bycatch) on yields to the directed fisheries

## References

Adlerstein, S. 1993. Comparison of Pacific halibut yield loss produced by bycatch in the trawl, longline, and pot Pacific cod fisheries in the Bering Sea. IPHC Report of Assessment and Research Activities 1992. p. 215-226.

Adlerstein, S.A. 1994. Spatial and temporal variation of Pacific halibut bycatch in Pacific cod domestic fisheries in the Bering Sea and losses inflicted to the halibut fishery. IPHC Report of Assessment and Research Activities 1993. p. 285-297.

Clark, W.G., and Hare, S.R. 1998. Accounting for bycatch in managment of the Pacific halibut fishery. North American Journal of Fisheries Management **18**: 809-821.

Goodyear, C.P. 1993. Spawning stock biomass per recruit in fisheries management: foundation and current use. Canadian Special Publication of Fisheries and Aquatic Sciences **120**: 67-81.

Hare, S.R., and Clark, W.G. 2007. Discussion paper on "regularizing" of bycatch, sport and subsistence catch. IPHC Report of Assessment and Research Activities 2006. p. 191-196.

Hare, S.R., and Williams, G.H. 2013. Coastwide estimates of lost CEY and FSBio from the bycatch of halibut in non-directed fisheries. IPHC Report of Assessment and Research Activities 2012. p. 355-372.

IPHC Secretariat. 2019a. Treatment and effects of Pacific halibut discard mortality (bycatch) in non-directed fisheries projected for 2019. IPHC-2019-AM095-INF07. 10 p.

IPHC Secretariat. 2019b. Additional harvest decision tables, treatment and effects of Pacific halibut discard mortality (bycatch) projected for 2020 and 2021, and time-series of bycatch and discard mortality. IPHC-2019-AM095-INF08. 11 p.

Martell, S., Stewart, I., and Sullivan, J. 2015. Implications of bycatch, discards, and size limits on reference points in the Pacific halibut fishery. *In* Fisheries bycatch: Global issues and creative solutions. *Edited by* G.H. Kruse and H.C. An and J. DiCosimo and C.A. Eischens and G. Gislason, S. and D.N. McBride and C.S. Rose and C.E. Siddon. Alaska Sea Grant, University of Alaska Fairbanks.

Martell, S.J.D., Leaman, B., Stewart, I.J., Keith, S.W., Joseph, C., Keizer, A., and Culver, M. 2016. Developments in management strategy evaluation / management strategy evaluation board. IPHC Report of Assessment and Research Activities 2015. p. 286-312.

Methot, R.D., Wetzel, C.R., and Taylor, I.G. 2019. Stock Synthesis User Manual Version 3.30.13. NOAA Fisheries. Seattle, WA. 213 p.

Salveson, S., Leaman, B.M., Low, L.L., and Rice, J.C. 1992. Report of the halibut bycatch work group. IPHC Tech. Rep. No. 25. 35 p.

Stewart, I., and Hicks, A. 2019a. 2019 Pacific halibut (*Hippoglossus stenolepis*) stock assessment: development. IPHC-2019-SRB014-07. 100 p.

Stewart, I., and Hicks, A. 2019b. Assessment of the Pacific halibut (*Hippoglossus stenolepis*) stock at the end of 2018. IPHC-2019-AM095-09. 26 p.

Sullivan, P.J., Trumble, R.J., and Adlerstein, S.A. 1994. Pacific halibut bycatch in the groundfish fisheries: effects on and management implications for the halibut fishery. IPHC Sci. Rep. No. 78. 28 p.