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Analysis of Catch Per Unit Effort Estimates Based on Hooking Order When More Than One Fish is Caught on a Hook

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Analysis of Catch Per Unit Effort Estimates Based on Hooking Order When More Than One Fish Is Caught on a Hook

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ABSTRACT

Catch per unit of effort (CPUE) is a common metric used to inform stock assessments. In the case of longline fishing, CPUE is often expressed as the number of fish per effective hook. In calculating the CPUE, assumptions are made about hook competition, gear placement, predation, etc. In this study we use survey data from two fishery-independent longline surveys operating in the eastern North Pacific Ocean (National Marine Fisheries Service, NMFS, Alaska Fisheries Science Center's groundfish longline survey and International Pacific Halibut Commission, IPHC, setline survey) to examine the impact of predation on CPUE. Both surveys only report one fish when more than one fish are caught on a single hook. The NMFS survey reports only the first-caught fish (prey), while the IPHC survey also reports the second-caught fish (predator), but uses only the second-caught fish in CPUE calculations. The purpose of this study was to examine if hooking order can impact estimates of CPUE. Two CPUE indices were calculated to analyze multiple fish per hook situations: 1) based only on the first hooked fish, and 2) based only on the second hooked fish. Unequal variances t-tests on ranks and bootstrapped confidence intervals were used for comparing the two CPUEs. The only species in which a significant change in the CPUE was observed was for octopus in both the NMFS survey ($n = 19$, $p < 0.001$) and in the 2007, 2009, and 2010 IPHC survey ($n = 12, 11$, and 22; $p < 0.0001$ for 2007 and <0.001 for 2009 and 2010). In general, it was found that there is no significant effect on CPUE depending on which fish is reported.

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INTRODUCTION

Fish stock assessments are based on fishery-dependent and -independent data sources, and they assume that those data sources are accurate and precise. Metrics of catch, either absolute such as total catch, or relative such as catch-per-unit-effort (CPUE), are generally the basis for most stock assessment models. CPUE is dependent on data inputs and estimation methods and varies greatly between gear types, fisheries, and standardizations. Thus, for stock assessments, it is critical to have an understanding of the data source and how CPUE is estimated.

This study examines the CPUE estimates (calculated for this study as the number of fish of each species per effective hook at a station) from two fishery-independent longline surveys operating in the eastern North Pacific which are used to inform groundfish stock assessments: the International Pacific Halibut Commission (IPHC) annual halibut setline survey and the National Marine Fisheries Service (NMFS) Alaska Fisheries Science Center's annual groundfish longline survey. Both surveys provide data from which CPUE estimates can be calculated, however the data recording methods differ. This study is not comparing the two surveys to each other but compares how the estimated CPUEs may change based on the method of data recording; thus, each survey is being compared to itself.

Estimating CPUE from longline data requires making assumptions about hook competition, hook shyness, predation of hooked fish and other considerations. This analysis examines the impact of predation of hooked fish on CPUE estimates. In discussing this phenomenon, we refer to the first-caught fish as the "prey" and the fish that subsequently tries to eat the prey as the "predator." A predation event can have four outcomes: 1) prey is hooked, predator partially eats prey but does not get hooked and leaves partially eaten prey on the hook; 2) prey is hooked, predator completely eats prey and is also hooked but prey is not observed since it is fully ingested; 3) prey is hooked, predator fully eats prey but does not get hooked and hook is left empty; and 4) prey is hooked, predator attempts to eat or partially eats prey and is also hooked; both prey and predator are readily observed. In Case 1, the prey species is still counted but not the predator, however, the predator is not considered a removal because it was not hooked, thus is not a concern. Cases 2 and 3 result in either only the predator observed on the hook or no hooked fish at all, and because it is impractical to examine the gut contents of every fish caught, observing and recording instances of Case 2 are rare (also assuming no regurgitation). Thus, Cases 2 and 3 are unobservable and assumed unknown. Case 4 is observable and data do exist to examine the impact on CPUE estimates.

The NMFS survey records only the prey (i.e., first fish hooked) and ignores any other animals on the hook. The IPHC survey records the predator (i.e., second fish hooked), ignoring the prey. Predation and the effect it may have on CPUE data has not previously been examined in these survey data. The objective of this project was to examine data from each survey to determine if the method of recording hooked animals (i.e., first or second on the hook) could cause a significant change in CPUE estimates.

METHODS

Data from each survey were provided for this analysis by the respective organizations. The IPHC survey operates along the extent of the United States and Canadian west coasts and north through Alaska waters (Goen et al. 2018). The IPHC survey systematically samples areas of Pacific halibut (*Hippoglossus stenolepis*) habitat, and thus the stations are located in waters shallower than 500 m (i.e., continental shelf) including nearshore areas. Approximately 1,200 stations are sampled in the standard grid, consisting of standardized sets of 5-6 skates of gear, each skate consisting of 100 16/0 circle hooks baited with chum salmon (*Oncorhynchus keta*) and spaced 5.5 m apart. A complete census of hooks is recorded at stations within Canadian waters, thus only data from those stations are used in this study.

In contrast, the NMFS survey was designed to sample exploitable sablefish habitat in the Gulf of Alaska, Bering Sea and Aleutian Islands, ranging from approximately 150 m – 1,000 m split into eight depth strata (Lunsford et al. 2018). This survey systematically samples approximately 87 stations each year, with two sets deployed at most stations. Gear configuration is standardized and each set consists of 80 skates of gear. Each skate is 100 m with 45 13/0 circle hooks spaced 2 m apart and baited with squid. This survey records a complete census of all hooks brought onboard. For both surveys, the relevant data recorded are the total number of hooks, the number of observed hooks, the number of observed ineffective hooks and the number of observed fish caught at each station.

The NMFS survey does not normally record instances when more than one fish per hook occurs: only the first fish (prey) is recorded in the NMFS data. Thus a special project was conducted during the 2014 survey to record any instances when two fish (prey and predator) were caught on a single hook at each station. Data on depth or location along the groundline were not available so stratification by depth were not possible. The NMFS data were not further stratified by area due to the small number of stations in which predation events were reported in each area. In most survey regions, the IPHC also does not record instances when more than one fish per hook occurs; this survey normally records only the predator. However, in Canadian waters the survey records both the prey and predator as part of normal survey operations. IPHC provided full hook census data for the years 2004 – 2014 for stations in Canadian waters. The IPHC data were summarized at the station level so that the resolution of the two surveys were similar. The methods used in this paper are not directly comparable to those used in stock assessments because of the lack of area and depth stratification. However, we did examine the occurrences of multiple fish per hook within the NMFS survey data with regards to management areas.

The analyses conducted in this report examine data at the species level with some exceptions. Several species categories were combined for this analysis due to rarity of catch or similarity to other species categories.

The CPUE metric used in this project was calculated as the number of fish caught by species divided by the total number of effective hooks (total hooks minus ineffective hooks) at a station. The total catch is all recorded catch of that species; total hooks is the number of hooks retrieved; and ineffective hooks are hooks that are bent, broken, snarled, or missing. The data were divided into two categories: first-caught (primary) fish and second-caught (secondary) fish. A primary ($CPUE_p$) and a secondary ($CPUE_s$) were calculated for each species in which predation events occurred, with the primary being the CPUE based on the first hooked fish (prey) and the secondary being based on whether or not a second hooked fish (predator) was observed. For example, if shortspine thornyhead (*Sebastolobus alascanus*) were caught on 25 out of 100 effective hooks the $CPUE_p$ would be 0.25, but if in 10 of those cases it was preyed upon, the $CPUE_s$ would be 0.15. For all instances when only one fish was on a hook the $CPUE_p$ and $CPUE_s$ are equal.

The CPUEs calculated for each station were used to calculate a mean across all stations for each species within each year. The number of stations with a CPUE for any given species is the sample size. An unequal variances t-test (Welch's Test) on the ranks of the mean was performed between the mean $CPUE_p$ and $CPUE_s$. The unequal variances t-test performed on ranks has been shown to be robust against unequal variances and non-normally distributed data (Zimmerman and Zumbo 1993, Ruxton 2006). All tests were performed at α = 0.05. Bootstrap methods were used to estimate confidence intervals about the mean CPUE. Data were resampled with replacement and new $CPUE_p$ and $CPUE_s$ were calculated with mean CPUE for the strata, which was replicated 1,000 times. The adjusted bootstrap percentile (BC_a) confidence intervals were used to estimate the 95% confidence intervals to adjust for any bias that may exist in the data (Efron and Tibshirani 1986). All analyses were conducted in R version 3.4.1 (R Development Core Team 2017).

RESULTS

A total of 118 species occur in the IPHC data; 29 of those species were preyed upon by a second hooked fish. The results of the unequal variances t-tests for the IPHC survey are shown in Table 1. With the exception of the 2007, 2009, and 2010 octopus, none of the species and years had a significant difference between $CPUE_p$ and $CPUE_s$. The mean CPUE and bootstrapped confidence intervals are presented in Table 2. The BC_a confidence intervals of the $CPUE_p$ and $CPUE_s$ are overlapping in most of the species and years, with a few exceptions (e.g., 2007, 2009, and 2010 octopus). The difference between the $CPUE_p$ and $CPUE_s$ for the four species which showed the greatest differences (octopus family Octopodidae, thornyhead *Sebastolobus* spp., darkblotched rockfish *Sebastes crameri*, and sixgill shark *Hexanchus griseus*) were plotted for each year in Figure 1.

The NMFS survey captured 36 total species, 31 of which were preyed upon. The results of the unequal variances t-tests for the NMFS survey are presented in Table 3. Similar to the IPHC survey, only octopus had significantly different $CPUE_p$ and $CPUE_s$ based on the unequal variances t-tests. The mean $CPUE_p$ and $CPUE_s$ with bootstrapped confidence intervals are presented in Table 4. The confidence intervals of the $CPUE_p$ and $CPUE_s$ are overlapping, with the exception of octopus. The difference between $CPUE_p$ and $CPUE_s$ for the four species with the greatest differences (even if not significant) in the NMFS survey (octopus, shortspine thornyhead, lingcod *Ophiodon elongates* and Pacific cod *Gadus macrocephalus*) are plotted in Figure 2.

Within the NMFS survey, there was no apparent trend in occurrences of multiple fish per hook. Multiple fish per hook occurred at between 71% and 94% of stations depending on management area, by hook at 0.04-0.1% of hooks within a management area. The areas with the highest (Western GOA) and lowest (Aleutian Islands) rates of occurrences were adjacent to each other.

DISCUSSION

Results of this analysis suggest that in general, recording either the first or second fish on a hook has little impact on the mean CPUE, with a few exceptions. Octopus was the only species in either survey where both the unequal variances t-test and the BC_a suggested a significant difference between $CPUE_p$ and $CPUE_s$. However, the change in mean CPUE and overlapping BC_a identified darkblotched rockfish, greenling (*Hexagrammos* spp.), octopus and sixgill shark as species with potential for significant differences in CPUE based on hooking order for the IPHC survey (Table 2). The darkblotched rockfish and greenling are both prey species in which the secondary CPUE was significantly decreased because a predator was the fish of record, while the octopus and sixgill sharks are both predator species and the opposite is true. The analysis of the NMFS survey identified octopus as the only species to have significant differences in CPUE for either test, with the secondary CPUE being significantly greater than the primary CPUE.

The difference in the results between the two tests for the IPHC survey data suggests different sensitivities for each test. The unequal variances t-test was less sensitive than the BC_a. Given the unequal variances t-test's robustness to non-normality and unequal variances when performed on ranks, this test is likely the most reliable (Zar 2010).

A possible reasoning for why most CPUEs show no dependence on which fish is recorded is that the occurrence of two fish on the same hook is relatively rare. Of the 1,833,568 effective hooks analyzed in this study (both surveys combined), 601,449 (33%) had catch of fish recorded. Of these, only 997 (0.17%) also had a secondary catch recorded. Another concern is that for this analysis the data were summarized at the station level and any differences in depth or geographical area would not be detected. It is possible that conducting this analysis at similar area and depth stratifications to what is used for computing survey indices used in stock assessment may have different results for some strata/areas. However, using the NMFS survey data suggest that area is not a factor, at least not within the GOA. Data do not exist for examining depth. The two surveys operate in different depths and different areas, so it is difficult to unconfound those variables.

These results show that while the overall impact of hooking order on CPUE is minimal, some predation effects are evident. Octopus, multiple species of shark, and lingcod are the most common second fish (predator) on a hook for both surveys. For the IPHC survey of the 198 recorded octopus catches, 29% of which had octopus as the predator, and two encounters with octopus as a prey species. In the NMFS data, octopus were recorded as predators 63% of the 138 times they were caught and only once as a prey. The first recorded catch (prey) species when octopus was the predator included Pacific cod, spiny dogfish, sablefish, and Pacific halibut suggesting octopus predation events were likely opportunistic and not focused on a select group of species. It should be noted that the data from each of these surveys are from different geographical regions, and there may be a regional effect in predator or prey based on where catches occur.

Further analyses of multiple fish events would benefit from stratifying data by area or depths and computing abundance indices similar to those used in stock assessments. Including additional years of data from the NMFS survey and including a broader geographic range for the IPHC survey would increase statistical power and help detect significant differences. However, this analysis showed that the occurrence of two fish on the same hook is relatively rare and the overall impact of how hooking order is recorded has minimal effect on CPUE. Therefore, for these two surveys, the results of this analysis indicate that changes to hooking order data collection procedures are likely not warranted.

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CITATIONS

Efron, B., and R. Tibshirani. 1986. Bootstrap methods for standard errors, confidence intervals and other measures of statistical accuracy. Stat, Sci. 1:54–77.

Goen, J., T. Geernaert, E. Henry, E. Soderlund, A. Ranta, T. Kong, and J. Forsberg. 2018. Fishery-independent setline survey (FISS) design and implementation in 2017, including current and future expansions. International Pacific Halibut Commission, IPHC-2018-AM094-06 Rev1: 1–44.

Menon, M. M., V. F. Gallucci, and L. L. Conquest. 2005. Sampling designs for the estimation of longline bycatch. Pages 851–870 *in* G. H. Kruse, V. F. Galluci, D. E. Hay, R. I. Perry, R. M. Peterman, T. C. Shirley, P. D. Spencer, B. Wilson, and D. Woodby (editors), Fisheries assessment and management in data-limited situations. Alaska Sea Grant College Program AK-SG-05-02, Fairbanks, AK.

R Development Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Ruxton, G. D. 2006. The unequal variance t-test is an underused alternative to Student's t-test and the Mann–Whitney U test. Behavioral Ecol. 17:688–690.

Lunsford, C., C. Rodgveller, and P. Malecha. 2018. The 2017 longline survey of the Gulf of Alaska and eastern Bering Sea on the FV *Ocean Prowler*: Cruise Report OP-17-01. AFSC Processed Rep. 2018-01, 30 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 17109 Lena Point Loop Road, Juneau, AK 99801.

Zar, J. H. 2010. Biostatistical Analysis (5th ed.). Upper Saddle River, N.J. Prentice-Hall/Pearson.

Zimmerman, D. W., and B. D. Zumbo. 1993. Rank transformations and the power of the Student *t* test and Welch *t'* test for non-normal populations with unequal variances. Can. J. of Exp. Psychol. 47:523–539.

Table 1. -- Results of the unequal variances t-test for each species and year combination which had both a $CPUE_p$ and $CPUE_s$ in the IPHC dataset. The sample size (n) for that species is the number of stations within that species/year combination. Significant results are notated with *.

Species	Year	p-value	n	Species	Year	p-value	n
Aleutian Skate	2008	0.8955	47	Lingcod	2009	0.8598	91
Arrowtooth Flounder	2007	0.7954	88	Lingcod	2010	0.8808	73
Arrowtooth Flounder	2008	0.7876	200	Lingcod	2011	0.6952	71
Arrowtooth Flounder	2009	0.8020	112	Lingcod	2012	0.9593	80
Arrowtooth Flounder	2010	0.7595	118	Lingcod	2013	0.6956	5
Arrowtooth Flounder	2011	0.6931	101	Longnose Skate	2007	0.9742	118
Arrowtooth Flounder	2012	0.8631	113	Longnose Skate	2008	0.9065	260
Arrowtooth Flounder	2013	0.7256	8	Longnose Skate	2009	0.9039	144
Arrowtooth Flounder	2014	0.9822	95	Longnose Skate	2010	0.8847	140
Benthic Invertebrates	2008	1.0000	95	Longnose Skate	2011	0.8140	141
Benthic Invertebrates	2010	1.0000	50	Longnose Skate	2012	0.9152	151
Benthic Invertebrates	2011	1.0000	101	Octopus	2007	< 0.0001*	12
Benthic Invertebrates	2012	1.0000	21	Octopus	2008	0.7984	9
Benthic Invertebrates	2014	1.0000	51	Octopus	2009	0.0049*	11
Big Skate	2007	0.3245	31	Octopus	2010	0.0017*	22
Big Skate	2008	0.8128	81	Octopus	2011	0.2259	14
Big Skate	2009	0.8616	46	Octopus	2012	0.1403	12
Big Skate	2010	0.9708	54	Pacific Cod	2007	0.8989	22
Big Skate	2011	0.5266	55	Pacific Cod	2008	0.6838	86
Big Skate	2012	0.8358	53	Pacific Cod	2009	0.8699	48
Big Skate	2013	0.5968	6	Pacific Cod	2010	0.9604	44
Canary Rockfish	2007	0.8811	13	Pacific Cod	2011	0.9708	54
Canary Rockfish	2008	0.8997	32	Pacific Cod	2012	0.8835	47
Canary Rockfish	2009	0.9901	21	Pacific Halibut	2007	0.9459	167
Canary Rockfish	2012	0.5730	14	Pacific Halibut	2008	0.9197	320
Darkblotched Rockfish	2008	0.2929	2	Pacific Halibut	2009	0.9561	170
Great Sculpin	2012	0.5000	2	Pacific Halibut	2010	0.9272	168
Greenling	2014	0.2929	2	Pacific Halibut	2011	0.8699	174
Lingcod	2007	0.8297	75	Pacific Halibut	2012	0.9381	181
Lingcod	2008	0.7440	174	Pacific Halibut	2013	0.9516	15

Table 1. – Cont.

Species	Year	p-value	n	Species	Year	p-value	n
Pacific Halibut	2014	0.9980	184	Sixgill Shark	2014	0.6296	5
Quillback Rockfish	2007	0.9139	23	Sleeper Shark	2008	0.9238	25
Quillback Rockfish	2008	0.9160	48	Sleeper Shark	2012	0.8503	3
Quillback Rockfish	2009	0.9935	28	Soupfin Shark	2010	0.9821	14
Quillback Rockfish	2010	0.9798	33	Spiny Dogfish	2007	0.9908	170
Quillback Rockfish	2011	0.9735	32	Spiny Dogfish	2008	0.9970	302
Quillback Rockfish	2012	0.9433	24	Spiny Dogfish	2009	1.0000	170
Redbanded Rockfish	2007	0.9928	66	Spiny Dogfish	2010	0.9946	167
Redbanded Rockfish	2008	0.9611	141	Spiny Dogfish	2011	0.9893	178
Redbanded Rockfish	2009	0.9956	76	Spiny Dogfish	2012	0.9984	178
Redbanded Rockfish	2010	0.9970	75	Spiny Dogfish	2014	0.9943	187
Redbanded Rockfish	2011	0.9949	69	Spotted Ratfish	2007	0.9657	19
Redbanded Rockfish	2012	0.9802	74	Spotted Ratfish	2008	0.9971	48
Rougheye Rockfish	2008	0.9028	54	Spotted Ratfish	2011	0.9889	31
Rougheye Rockfish	2012	0.9569	23	Starfish	2009	1.0000	61
Sablefish (blackcod)	2007	0.9075	82	Starfish	2010	1.0000	96
Sablefish (blackcod)	2008	0.8721	176	Starfish	2011	1.0000	90
Sablefish (blackcod)	2009	0.9174	103	Steller Sea Lion	2009	0.1560	2
Sablefish (blackcod)	2010	0.8902	98	Thornyhead	2008	0.9701	59
Sablefish (blackcod)	2011	0.8721	90	Thornyhead	2009	0.8779	28
Sablefish (blackcod)	2012	0.8822	94	Thornyhead	2010	0.9162	28
Sablefish (blackcod)	2013	0.7637	6	Thornyhead	2011	0.9595	24
Scallop	2010	0.7705	2	Walleye Pollock	2008	0.7987	10
Silvergray Rockfish	2007	0.8709	24	Yelloweye Rockfish	2008	0.9748	129
Silvergray Rockfish	2008	0.9136	67	Yelloweye Rockfish	2009	0.9787	74
Silvergray Rockfish	2010	0.8839	32	Yelloweye Rockfish	2010	0.9912	67
Silvergray Rockfish	2011	0.9677	28	Yelloweye Rockfish	2011	0.9982	65
Sixgill Shark	2011	0.0710	4	Yelloweye Rockfish	2012	0.9939	61

Table 2. -- Mean $CPUE_p$ and $CPUE_s$ with bootstrapped 95% bias-corrected confidence intervals (in parentheses) for each species and year combination with both $CPUE_p$ and $CPUE_s$ in the IPHC dataset. Significant results are notated with *.

Species	Year	$CPUE_p$	$CPUE_s$
Aleutian Skate	2008	0.0075 (0.0052, 0.0122)	0.0076 (0.0053, 0.0127)
Arrowtooth Flounder	2007	0.0167 (0.0131, 0.0232)	0.0160 (0.0125, 0.0223)
Arrowtooth Flounder	2008	0.0204 (0.0175, 0.0244)	0.0199 (0.0169, 0.0239)
Arrowtooth Flounder	2009	0.0246 (0.0198, 0.0312)	0.0242 (0.0194, 0.0304)
Arrowtooth Flounder	2010	0.0215 (0.0162, 0.0292)	0.0212 (0.0158, 0.0299)
Arrowtooth Flounder	2011	0.0208 (0.0157, 0.0385)	0.0198 (0.0151, 0.0353)
Arrowtooth Flounder	2012	0.0227 (0.0177, 0.0304)	0.0221 (0.0178, 0.0311)
Arrowtooth Flounder	2013	0.0093 (0.0045, 0.0154)	0.0087 (0.0038, 0.0146)
Arrowtooth Flounder	2014	0.0137 (0.0100, 0.0193)	0.0137 (0.0103, 0.0202)
Benthic Invertebrates	2008	0.0030 (0.0026, 0.0037)	0.0030 (0.0026, 0.0037)
Benthic Invertebrates	2010	0.0024 (0.0016, 0.0048)	0.0023 (0.0016, 0.0045)
Benthic Invertebrates	2011	0.0050 (0.0036, 0.0084)	0.0050 (0.0036, 0.0088)
Benthic Invertebrates	2012	0.0040 (0.0030, 0.0066)	0.0039 (0.0029, 0.0062)
Benthic Invertebrates	2014	0.0037 (0.0028, 0.0056)	0.0036 (0.0027, 0.0052)
Big Skate	2007	0.0052 (0.0038, 0.0069)	0.0066 (0.0050, 0.0094)
Big Skate	2008	0.0053 (0.0043, 0.0066)	0.0055 (0.0045, 0.0068)
Big Skate	2009	0.0036 (0.0027, 0.0051)	0.0036 (0.0028, 0.0053)
Big Skate	2010	0.0051 (0.0039, 0.0069)	0.0052 (0.0039, 0.0072)
Big Skate	2011	0.0057 (0.0038, 0.0118)	0.0064 (0.0043, 0.0123)
Big Skate	2012	0.0066 (0.0052, 0.0098)	0.0071 (0.0054, 0.0108)
Big Skate	2013	0.0055 (0.0017, 0.0115)	0.0060 (0.0025, 0.0118)
Canary Rockfish	2007	0.0033 (0.0025, 0.0046)	0.0031 (0.0022, 0.0044)
Canary Rockfish	2008	0.0055 (0.0044, 0.0067)	0.0054 (0.0043, 0.0067)
Canary Rockfish	2009	0.0048 (0.0028, 0.0080)	0.0047 (0.0028, 0.0077)
Canary Rockfish	2012	0.0034 (0.0029, 0.0045)	0.0031 (0.0023, 0.0042)
Darkblotched Rockfish	2008	0.0031 (0.0021, 0.0031)*	0.0021 (0.0020, 0.0021)*
Greenling	2014	0.0029 (0.0015, 0.0029)*	0.0014 (0.0014, 0.0014)*
Lingcod	2007	0.0090 (0.0069, 0.0124)	0.0091 (0.0072, 0.0129)
Lingcod	2008	0.0126 (0.0106, 0.0153)	0.0129 (0.0107, 0.0155)
Lingcod	2009	0.0079 (0.0062, 0.0106)	0.0081 (0.0061, 0.0105)
Lingcod	2010	0.0055 (0.0043, 0.0073)	0.0056 (0.0044, 0.0075)
Lingcod	2011	0.0056 (0.0044, 0.0075)	0.0057 (0.0045, 0.0076)
Lingcod	2012	0.0098 (0.0078, 0.0133)	0.0098 (0.0079, 0.0135)

Table 2. – Cont.

Species	Year	$CPUE_p$	$CPUE_s$
Lingcod	2013	0.0027 (0.0017, 0.0040)	0.0024 (0.0010, 0.0040)
Longnose Skate	2007	0.0111 (0.0091, 0.0141)	0.0111 (0.0088, 0.0140)
Longnose Skate	2008	0.0143 (0.0126, 0.0164)	0.0145 (0.0128, 0.0165)
Longnose Skate	2009	0.0124 (0.0108, 0.0148)	0.0125 (0.0107, 0.0148)
Longnose Skate	2010	0.0123 (0.0107, 0.0144)	0.0125 (0.0108, 0.0143)
Longnose Skate	2011	0.0109 (0.0095, 0.0126)	0.0112 (0.0096, 0.0130)
Longnose Skate	2012	0.0178 (0.0150, 0.0211)	0.0180 (0.0154, 0.0212)
Octopus	2007	0.0003 (0.0000, 0.0008)*	0.0025 (0.0020, 0.0039)*
Octopus	2008	0.0018 (0.0011, 0.0025)	0.0020 (0.0020, 0.0020)
Octopus	2009	0.0008 (0.0004, 0.0012)*	0.0023 (0.0017, 0.0040)*
Octopus	2010	0.0008 (0.0005, 0.0013)*	0.0018 (0.0015, 0.0024)*
Octopus	2011	0.0010 (0.0005, 0.0013)	0.0016 (0.0010, 0.0017)
Octopus	2012	0.0021 (0.0013, 0.0031)	0.0031 (0.0025, 0.0049)
Pacific Cod	2007	0.0056 (0.0031, 0.0107)	0.0057 (0.0034, 0.0114)
Pacific Cod	2008	0.0084 (0.0067, 0.0104)	0.0080 (0.0065, 0.0101)
Pacific Cod	2009	0.0029 (0.0024, 0.0039)	0.0028 (0.0023, 0.0039)
Pacific Cod	2010	0.0042 (0.0030, 0.0061)	0.0042 (0.0030, 0.0060)
Pacific Cod	2011	0.0084 (0.0058, 0.0130)	0.0083 (0.0058, 0.0120)
Pacific Cod	2012	0.0063 (0.0049, 0.0091)	0.0062 (0.0049, 0.0092)
Pacific Halibut	2007	0.0595 (0.0524, 0.0680)	0.0597 (0.0524, 0.0686)
Pacific Halibut	2008	0.0879 (0.0801, 0.0966)	0.0883 (0.0808, 0.0970)
Pacific Halibut	2009	0.0791 (0.0711, 0.0886)	0.0794 (0.0719, 0.0906)
Pacific Halibut	2010	0.0808 (0.0704, 0.0915)	0.0811 (0.0702, 0.0939)
Pacific Halibut	2011	0.0639 (0.0563, 0.0742)	0.0643 (0.0565, 0.0734)
Pacific Halibut	2012	0.1211 (0.1091, 0.1346)	0.1216 (0.1086, 0.1336)
Pacific Halibut	2013	0.0403 (0.0279, 0.0551)	0.0409 (0.0272, 0.0547)
Pacific Halibut	2014	0.0748 (0.0664, 0.0838)	0.0748 (0.0668, 0.0852)
Quillback Rockfish	2007	0.0108 (0.0076, 0.0159)	0.0107 (0.0075, 0.0158)
Quillback Rockfish	2008	0.0110 (0.0079, 0.0253)	0.0108 (0.0075, 0.0212)
Quillback Rockfish	2009	0.0094 (0.0066, 0.0156)	0.0093 (0.0067, 0.0149)
Quillback Rockfish	2010	0.0097 (0.0071, 0.0138)	0.0096 (0.0069, 0.0130)
Quillback Rockfish	2011	0.0097 (0.0070, 0.0128)	0.0095 (0.0068, 0.0130)
Quillback Rockfish	2012	0.0120 (0.0086, 0.0163)	0.0119 (0.0087, 0.0165)
Redbanded Rockfish	2007	0.0230 (0.0175, 0.0320)	0.0229 (0.0170, 0.0326)

Table 2. -- Cont.

Species	Year	$CPUE_p$	$CPUE_s$
Redbanded Rockfish	2008	0.0242 (0.0199, 0.0308)	0.0241 (0.0197, 0.0309)
Redbanded Rockfish	2009	0.0374 (0.0296, 0.0503)	0.0374 (0.0291, 0.0488)
Redbanded Rockfish	2010	0.0274 (0.0206, 0.0373)	0.0274 (0.0209, 0.0378)
Redbanded Rockfish	2011	0.0241 (0.0179, 0.0326)	0.0241 (0.0182, 0.0332)
Redbanded Rockfish	2012	0.0297 (0.0230, 0.0375)	0.0296 (0.0234, 0.0381)
Rougheye Rockfish	2008	0.0149 (0.0102, 0.0258)	0.0149 (0.0098, 0.0240)
Rougheye Rockfish	2012	0.0189 (0.0107, 0.0345)	0.0188 (0.0106, 0.0350)
Sablefish (blackcod)	2007	0.0501 (0.0394, 0.0628)	0.0498 (0.0392, 0.0631)
Sablefish (blackcod)	2008	0.0575 (0.0483, 0.0670)	0.0570 (0.0484, 0.0667)
Sablefish (blackcod)	2009	0.0475 (0.0370, 0.0599)	0.0474 (0.0364, 0.0587)
Sablefish (blackcod)	2010	0.0525 (0.0430, 0.0650)	0.0519 (0.0427, 0.0627)
Sablefish (blackcod)	2011	0.0512 (0.0407, 0.0631)	0.0505 (0.0399, 0.0630)
Sablefish (blackcod)	2012	0.0537 (0.0433, 0.0692)	0.0531 (0.0429, 0.0673)
Sablefish (blackcod)	2013	0.0101 (0.0059, 0.0152)	0.0093 (0.0047, 0.0135)
Scallop	2010	0.0220 (0.0013, 0.0428)	0.0214 (0.0013, 0.0214)
Silvergray Rockfish	2007	0.0055 (0.0039, 0.0084)	0.0054 (0.0037, 0.0083)
Silvergray Rockfish	2008	0.0071 (0.0052, 0.0105)	0.0070 (0.0050, 0.0107)
Silvergray Rockfish	2010	0.0034 (0.0026, 0.0050)	0.0033 (0.0025, 0.0045)
Silvergray Rockfish	2011	0.0079 (0.0047, 0.0135)	0.0077 (0.0045, 0.0139)
Sixgill Shark	2011	0.0009 (0.0000, 0.0013)*	0.0099 (0.0017, 0.0180)*
Sixgill Shark	2014	0.0070 (0.0017, 0.0133)	0.0091 (0.0025, 0.0161)
Sleeper Shark	2008	0.0093 (0.0058, 0.0149)	0.0100 (0.0060, 0.0159)
Sleeper Shark	2012	0.0045 (0.0025, 0.0065)	0.0036 (0.0025, 0.0056)
Soupfin Shark	2010	0.0021 (0.0015, 0.0033)	0.0022 (0.0015, 0.0042)
Spiny Dogfish	2007	0.1544 (0.1374, 0.1723)	0.1543 (0.1367, 0.1745)
Spiny Dogfish	2008	0.1325 (0.1162, 0.1539)	0.1325 (0.1157, 0.1517)
Spiny Dogfish	2009	0.1632 (0.1420, 0.1844)	0.1631 (0.1454, 0.1844)
Spiny Dogfish	2010	0.1329 (0.1115, 0.1551)	0.1328 (0.1127, 0.1575)
Spiny Dogfish	2011	0.1385 (0.1197, 0.1588)	0.1383 (0.1199, 0.1597)
Spiny Dogfish	2012	0.1306 (0.1097, 0.1556)	0.1305 (0.1114, 0.1617)
Spiny Dogfish	2014	0.0852 (0.0726, 0.1018)	0.0852 (0.0720, 0.1004)
Spotted Ratfish	2007	0.0035 (0.0025, 0.0064)	0.0034 (0.0023, 0.0065)
Spotted Ratfish	2008	0.0047 (0.0038, 0.0063)	0.0047 (0.0037, 0.0062)
Spotted Ratfish	2011	0.0042 (0.0031, 0.0059)	0.0042 (0.0031, 0.0057)

Table 2. -- Cont.

Species	Year	$CPUE_p$	$CPUE_s$
Starfish	2009	0.0111 (0.0072, 0.0175)	0.0111 (0.0072, 0.0196)
Starfish	2010	0.0071 (0.0052, 0.0108)	0.0071 (0.0048, 0.0106)
Starfish	2011	0.0089 (0.0065, 0.0122)	0.0089 (0.0065, 0.0125)
Thornyhead	2008	0.0089 (0.0072, 0.0113)	0.0089 (0.0071, 0.0112)
Thornyhead	2009	0.0081 (0.0050, 0.0129)	0.0080 (0.0053, 0.0131)
Thornyhead	2010	0.0078 (0.0051, 0.0126)	0.0076 (0.0050, 0.0129)
Thornyhead	2011	0.0116 (0.0075, 0.0202)	0.0114 (0.0076, 0.0211)
Walleye Pollock	2008	0.0045 (0.0026, 0.0117)	0.0043 (0.0024, 0.0100)
Yelloweye Rockfish	2008	0.0268 (0.0213, 0.0348)	0.0267 (0.0209, 0.0346)
Yelloweye Rockfish	2009	0.0274 (0.0203, 0.0370)	0.0274 (0.0200, 0.0370)
Yelloweye Rockfish	2010	0.0330 (0.0240, 0.0506)	0.0330 (0.0234, 0.0505)
Yelloweye Rockfish	2011	0.0251 (0.0184, 0.0352)	0.0251 (0.0190, 0.0352)
Yelloweye Rockfish	2012	0.0367 (0.0270, 0.0530)	0.0367 (0.0270, 0.0524)

Table 3. -- Results of the unequal variances t-test for all of the species with both a $CPUE_p$ and $CPUE_s$ in the NMFS dataset. The sample size (n) for that species is the number of stations with that species/year combination. Significant results are notated with *.

Species	p-value	N
Aleutian Bering Alaska Skate Complex	0.9810	80
Arrowtooth Flounder	0.9845	87
Big Skate	0.9600	8
Commander Skate	0.9876	18
Darkfin Sculpin	0.9420	10
Dusky Rockfish	0.9710	10
Giant Grenadier	0.9730	60
Golden King Crab (Golden)	0.7345	9
Greenland Turbot	0.9420	10
Greenstriped Rockfish	0.8503	3
Lingcod	0.4822	12
Longnose Skate	0.8202	71
Northern Rockfish	0.7946	4
Octopus	0.0025*	19
Pacific Cod	0.9651	72
Pacific Grenadier	0.9924	25
Pacific Halibut	0.9761	87
Redbanded Rockfish	0.9973	51
Rosethorn Rockfish	0.9287	14
Sablefish	0.9904	87
Searcher	0.8271	10
Shortspine Thornyhead	0.9168	83
Sponge Unidentified	0.9973	51
Spotted Ratfish	0.9710	10
Tanner Crab Unident.	0.6932	4
Tanner Crab	0.5453	8
Walleye Pollock	0.9536	63
Whiteblotched Skate	0.9839	15
Whitebrow Skate	0.8189	6
Yellow Irish Lord	0.9331	12
Yelloweye Rockfish	0.9866	17

Table 4. -- Mean $CPUE_p$ and $CPUE_s$ with bootstrapped 95% bias-corrected confidence intervals (in parentheses) for each species both a $CPUE_p$ and $CPUE_s$ in the NMFS survey. Significant results are notated with *.

Species	$CPUE_p$	$CPUE_s$
Aleutian Bering Alaska Skate Complex	0.0112 (0.0072, 0.0216)	0.0112 (0.0073, 0.0199)
Arrowtooth Flounder	0.0174 (0.0142, 0.0217)	0.0174 (0.0145, 0.0216)
Big Skate	0.0004 (0.0003, 0.0009)	0.0005 (0.0002, 0.0010)
Commander Skate	0.0029 (0.0010, 0.0086)	0.0029 (0.0010, 0.0080)
Darkfin Sculpin	0.0065 (0.0026, 0.0140)	0.0065 (0.0024, 0.0139)
Dusky Rockfish	0.0028 (0.0004, 0.0119)	0.0028 (0.0004, 0.0099)
Giant Grenadier	0.1393 (0.1166, 0.1640)	0.1392 (0.1171, 0.1676)
Golden King Crab (Golden)	0.0009 (0.0004, 0.0025)	0.0010 (0.0004, 0.0026)
Greenland Turbot	0.0034 (0.0013, 0.0083)	0.0034 (0.0014, 0.0085)
Greenstriped Rockfish	0.0016 (0.0001, 0.0041)	0.0015 (0.0001, 0.0028)
Lingcod	0.0004 (0.0003, 0.0006)	0.0005 (0.0003, 0.0007)
Longnose Skate	0.0050 (0.0037, 0.0076)	0.0052 (0.0038, 0.0081)
Northern Rockfish	0.0023 (0.0011, 0.0030)	0.0022 (0.0011, 0.0030)
Octopus	0.0004 (0.0003, 0.0005)*	0.0009 (0.0007, 0.0013)*
Pacific Cod	0.0408 (0.0298, 0.0558)	0.0407 (0.0299, 0.0584)
Pacific Grenadier	0.0053 (0.0024, 0.0136)	0.0053 (0.0021, 0.0121)
Pacific Halibut	0.0231 (0.0188, 0.0300)	0.0231 (0.0186, 0.0294)
Redbanded Rockfish	0.0045 (0.0027, 0.0082)	0.0045 (0.0027, 0.0083)
Rosethorn Rockfish	0.0007 (0.0005, 0.0013)	0.0007 (0.0005, 0.0013)
Sablefish	0.1199 (0.1042, 0.1377)	0.1199 (0.1027, 0.1389)
Searcher	0.0003 (0.0002, 0.0006)	0.0003 (0.0002, 0.0005)
Shortspine Thornyhead	0.0315 (0.0274, 0.0369)	0.0313 (0.0273, 0.0362)
Sponge Unidentified	0.0013 (0.0009, 0.0024)	0.0013 (0.0010, 0.0023)
Spotted Ratfish	0.0049 (0.0011, 0.0123)	0.0049 (0.0010, 0.0123)
Tanner Crab Unident.	0.0002 (0.0001, 0.0003)	0.0002 (0.0001, 0.0003)
Tanner Crab	0.0002 (0.0002, 0.0003)	0.0003 (0.0002, 0.0003)
Walleye Pollock	0.0052 (0.0037, 0.0075)	0.0051 (0.0037, 0.0072)
Whiteblotched Skate	0.0163 (0.0043, 0.0523)	0.0163 (0.0050, 0.0587)
Whitebrow Skate	0.0004 (0.0002, 0.0005)	0.0004 (0.0002, 0.0005)
Yellow Irish Lord	0.0150 (0.0057, 0.0311)	0.0150 (0.0063, 0.0322)
Yelloweye Rockfish	0.0037 (0.0008, 0.0108)	0.0037 (0.0009, 0.0123)

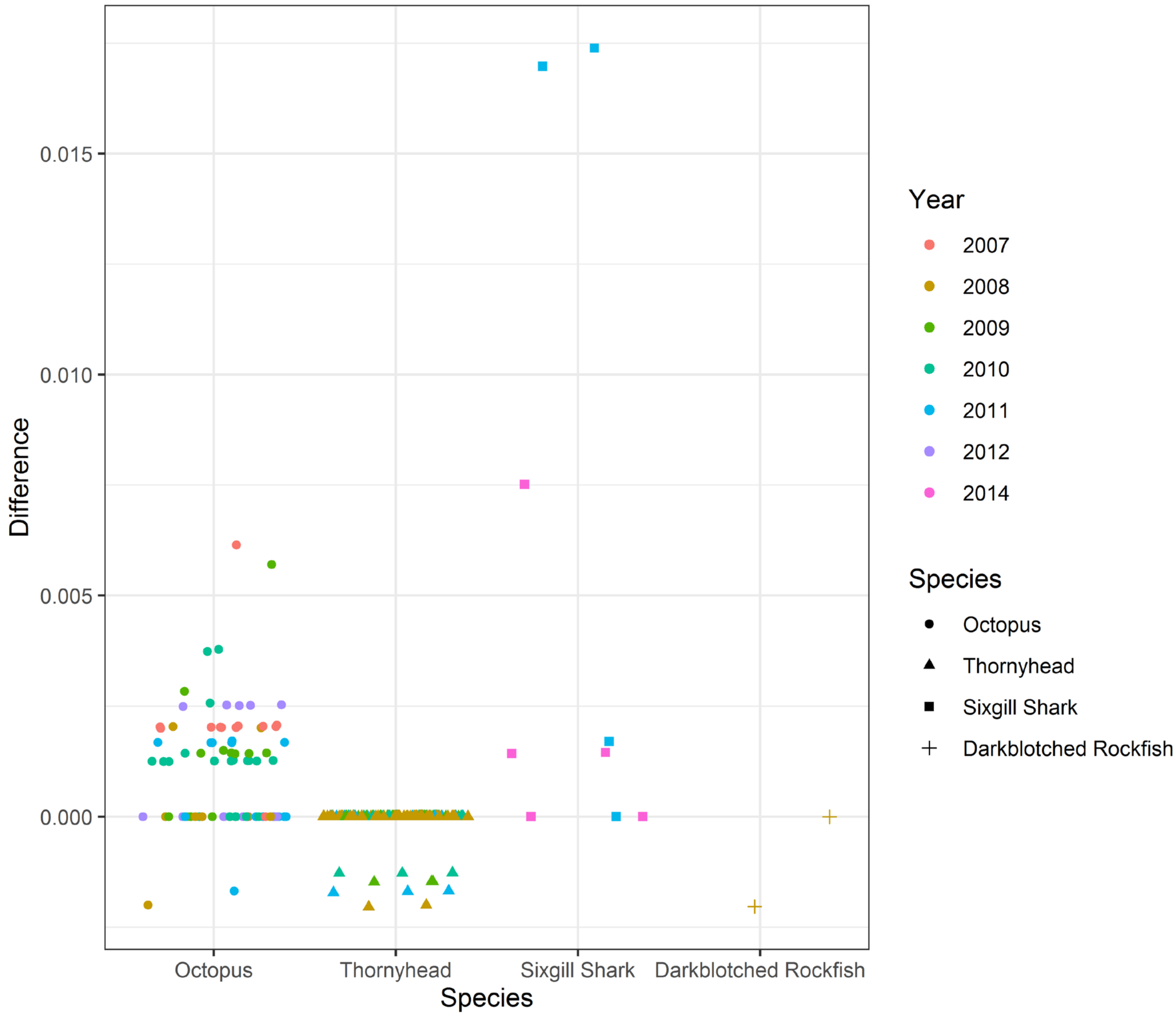

Figure 1. -- Difference between $CPUE_s$ and $CPUE_p$ for octopus, thornyhead, sixgill shark, and darkblotched rockfish from every year in which $CPUE_s$ varied from $CPUE_p$ in the IPHC survey. These four species had the greatest differences between $CPUE_s$ and $CPUE_p$. Positive values are when the $CPUE_s$ was greater than $CPUE_p$ and vice versa.

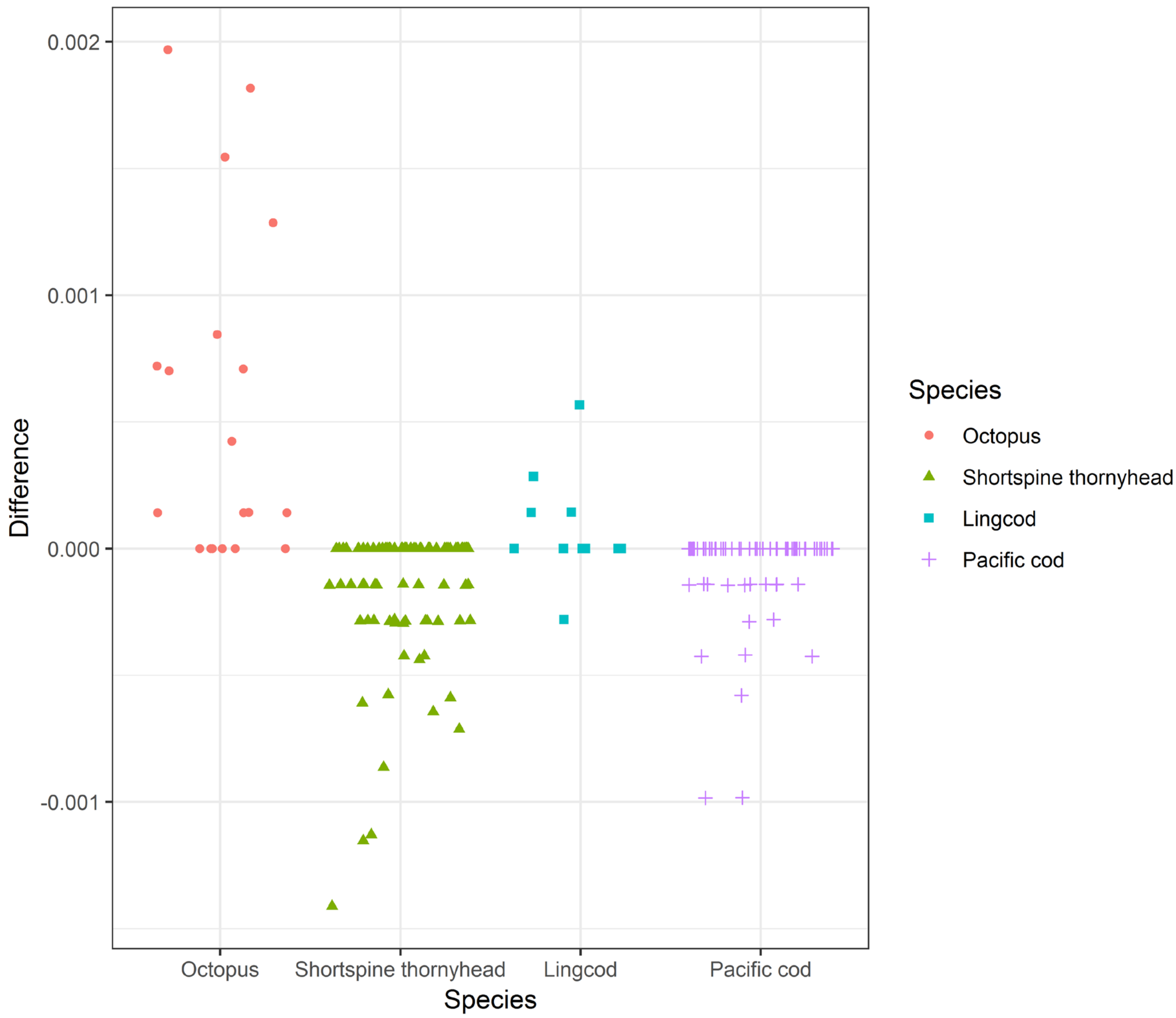

Figure 2. -- Difference between $CPUE_s$ and $CPUE_p$ for octopus, shortspine thornyhead, lingcod, and Pacific cod in the NMFS survey. These four species had the greatest differences between $CPUE_s$ and $CPUE_p$. Positive values are when the $CPUE_s$ was greater than $CPUE_p$ and vice versa.

U.S. Secretary of Commerce
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