Comparison of Sockeye Salmon catch and catch rates of two test-fishing gill nets used at Round Island in 2019.

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1. Acknowledgments

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2. Introduction

Maturing Sockeye salmon (*Oncorhynchus nerka*) head back to the Fraser River in the summer and are caught in test-fisheries along their migration routes for in-season assessment and fishery management purposes (i.e. run strength, timing and stock composition). Since 1997, Fisheries & Oceans Canada (DFO) conducted test fishing at various locations in BC using two types of gillnets (GN), namely a 60 mesh multi-strand net (MS60) and a 90 mesh Alaska-twist net (AT90).The mesh sizes are similar but the AT90 net is assumed to have greater catching power because it can intercept salmon deeper in the water column.

. In 2019, additional test-fishing was conducted at Round Island, with the same GN types and two vessels in a similar manner. The purpose of additional test fishing is to calibrate the catch-per-unit-effort (CPUE) patterns obtained with each net type so to maintain consistency in CPUE trends for future test fishing operations using only the AT90 net.

The objectives of the present investigation are to compare the trends in CPUE and catch composition for the AT90 and MS60 nets used during the 2019 test fishery. Methods proposed for the AT90/MS60 CPUE conversions, and determining uncertainty levels in CPUE are to be described. If need be, the 2019 trends could be compared with the pertinent results of previous years (2004-2005) when the two net types were fished together.

3. Materials and methods

Test fishing operations and timing

Details on net deployment and retrieval periods with catches of each species by date, time, location, net type, vessel ID, mesh type, mesh-depth (surface for MS60, and surface and deep for AT90) were collected from DFO's Fishery Operating System (FOS) Database. The 2019 test fishing started with one vessel fishing each night with a MS60 net from July 11 to August 10. Paired test-fishing sets using two vessels were conducted during July 16 to August 9.

Efforts were made to conduct paired sets four days per week. Two vessels conducted three sets each night about 0.5 km apart, starting around dusk. Night sets were those that took place between 7 p.m. and 8 a.m. the following morning, resulting in all sets being recorded as night sets in 2019. Vessels used either the MS60 or AT90 net the first two days, then swapped nets for the next two days. A total of 219 test-fishing records were provided, with all sets considered as good (no deployment/retrieval problems).

The MS60 nets has 30+ filaments in each twine, with filaments of equal diameter. The AT90 net has 6+ filaments, with filaments ≥0.20 mm in diameter. The Alaska-twist mesh is supposedly less visible to salmon and is less expensive to produce. The side lengths of the MS60 and AT90 nets are ~5.2” and ~5.0” respectively, so the nets have similar stretched mesh sizes measured as the distance between opposite corners of the square when stretched. The maximum depths reached by the MS60 and AT90 nets are ~26' and ~38' respectively. The horizontal lengths of the MS60 and AT90 nets are 200 and 205 fathoms respectively, but the difference is negligible so the lengths of both nets were set to 200 fathoms or 1200'.

The net areas (i.e. surface area or fishing area) can be expressed in net units, fathom^2, feet^2 or meter^2. For this report the net areas are expressed here in meter^2. For the MS60 and AT90 nets, the shallow portion (0-60 meshes) is 365.7 m in length by 7.9 m in depth for a total area of 2898.6 m^2. The deeper portion of the AT90 net is 365.7 in length by 3.6 m in depth for an area of 1337.8 m^2, and a total AT90 net area of 4236.4 m^2. The surface area of the MS60 net is about 0.68 that of the total area for the AT90 net (~ 2/3rd). Catch per unit effort values (CPUE) can be very small when the effort denominator is large relative to the catch. For the present investigation, net area is expressed as m^2/10000.

Fishing effort calculation

Test fishing gillnet sets are not always of the same duration. Fishing effort for seine, gillnet, and longline gears should account for soak times, usually expressed in hook·hours or net·hours (see Labelle 1998, Dauk and Schwarz 2000, Ward et al. 2004). This requires accounting for periods when not all the gear is potentially intercepting fish. One conventional effort measure used for gillnets is half the gear deployment period, plus the full gear fishing period, plus half the gear retrieval period. Fishing effort is computed separately for the shallow and deeper mesh panels of the AT90 net to facilitate comparisons. Let n=set number, d=depth (0-60 mesh=1, 61-90 mesh=2), and p=net handling periods (set=1, full=2, retrieve=3), basic area effort (E) and adjusted fishing effort (E') is computed as follows

[1] $$E'_n = \sum\left(\frac{E_{ndp=1}}{2} + E_{ndp=2} + \frac{E_{ndp=3}}{2}\right) \qquad \text{for } d=1,2$$

Three periods (in hours) were recorded for each set, so adjusted effort per set is computed in terms of net area·hours (m^2/10000 x h).

Sockeye CPUEs were computed for each test-fishing fishing incident (vessel, set, net mesh depth, period) from catch/adjusted effort. CPUEs can be highly variable because the gear catchabilities can vary in a log-normal fashion. To reduce some of the variation between sets, it is often helpful to pool catch and effort statistics from multiple sets by stratum (day). CPUEs are computed for individual sets by gear type, and with total catch and effort by net type/day using a simple ratio estimator (or Eq. 1 in Appendix 1, for details and justifications).

4. Results

The total set durations range was 1.1 to 4.7 hours with the longer sets generally the latest ones. Average set time was about 2.6 hours in 2019. The trends in Sockeye CPUE for the paired AT90 and MS60 sets, surface mesh depth only (Fig. 1) show that on occasion, the MS60 CPUE was greater than the AT90 one, namely on July 19 and25, and August 2,3 and 9. Such results can be caused by a combination of factors such a random variation in catchabilities, net deployment location, the presence of predators, etc. When comparing the surface and deeper mesh CPUEs for the AT90 net (Fig. 2), sometimes the surface mesh CPUE was greater than the deeper mesh CPUE even though that lower mesh panel has a smaller surface area. This could be caused by factors like swimming depth, luminosity levels, tidal influences and forage depth. The 2019 data set provided by DFO staff did not include measurements for ancillary variables, which precludes using more factors in the estimation of CPUEs. When comparing MS60 and AT90 CPUEs based on catch/effort (upper and lower mesh of AT90 net combined), the MS60 net CPUE was still on occasion greater than that of the AT90 net despite the larger net area of the latter (Fig. 3).

In the hope of reducing variation in catchabilities and CPUE, catch and effort statistics were pooled by net type and day (sum statistics for three sets/d). This showed that no Sockeye were caught by the AT90 net on July 30, August 2 and August 4, and none were caught by the MS60 net on August 4. Using all daily catch versus effort records by net types for paired fishing dates, a linear regression of catch versus effort showed no increase or decrease in catch versus effort. There is considerable variation around the regression line, with larger residuals above the line, as expected for log-normal catchability error. A simple linear regression daily CPUEs of AT90 against MS60 (Fig. 5) shows a ratio (or slope) of about 0.42, which implies that on average the AT90 net CPUE was less than half of the MS60 CPUE. However, the regression does not go through the origin, and the residuals are not well distributed, so using this regression estimate of relative performance is not well supported. A regression through the origin was also computed, and showed a slope of ~0.6, but the fit was not good, nor was the distribution of residuals.

Given the limitations of the regression estimates, AT90/MS60 CPUE ratio was re-computed with the arithmetic estimator (Eq. 2, Appendix 1). The ratio of the mean AT90 CPUE over the mean MS60 CPUE was 0.77, indicating a lower performance of the AT90 net in 2019. The mean of the daily ratios of AT90/MS60 CPUEs was greater or about 1.1, indicating a slightly greater performance of the AT90 net. So depending on the estimator chosen, and how one deals with lack of paired observations and seemingly aberrant records, it appears that the CPUE of the AT90 net was ~0.8 to 1.1 times greater than that of the MS60 net.

Despite the problems reported above, the results are not totally different that those obtained during the 2004-2005 sockeye test fishing season. Using pooled daily test fishing records, Labelle (2015) determined that the performance of the AT90 net was 1.2 times that of the MS60 net in 2004, but only 0.97 times of the MS60 net in 2005, indicating substantial year to year variation likely due to environmental conditions, run sizes, and operational difficulties. For 2019, at least one of the estimates presented above was very close to the findings in 2005.

5. Discussion and recommendations

By contrast to previous paired test-fishing period (2004-2005), determining a calibration factor for the AT90 versus MS60 net for the 2019 season was hampered by historically low Sockeye returns, low catches per set, no Sockeye catches in some days, days with no paired sets, a short test-fishing season, and little information on ancillary variables to filter-out potential outliers. Efforts were made to compensate for large variation in net and set-specific CPUE by pooling records by day, but this did not help much in all cases. Pooling could have been done using two day strata, but this would have reduced the number of comparable points to ten, which was considered insufficient.

Given the above, and somewhat inconclusive results obtained via this investigation, no further efforts were made to analyze and/or contrast CPUEs for other species caught during the test-fishing period. Also, no efforts were made to determine the actual variance of the CPUE trends, in part because the best estimation procedure for this data set remains to be determined. However, typically, bootstrap procedures are commonly used for this purpose once the outliers have been identified and removed.

In light of the above comments, it is recommended that paired test fishing be continued as planned in the future. Efforts should be made to conduct more paired sets and of same duration (ideally aim for 2h). When the Sockeye run is strong (as in 2004-2005), there was evidence of gear saturation for long duration sets (see Labelle 2015). Also in 2019, some sets were > 4h in duration, which potentially allows for greater removals by predators and net failure caused by debris build-up. In addition, the duration of the test fishery should be extended to ensure it covers the beginning, peak and end of the Sockeye run, so that adjustments could be made for run timing.

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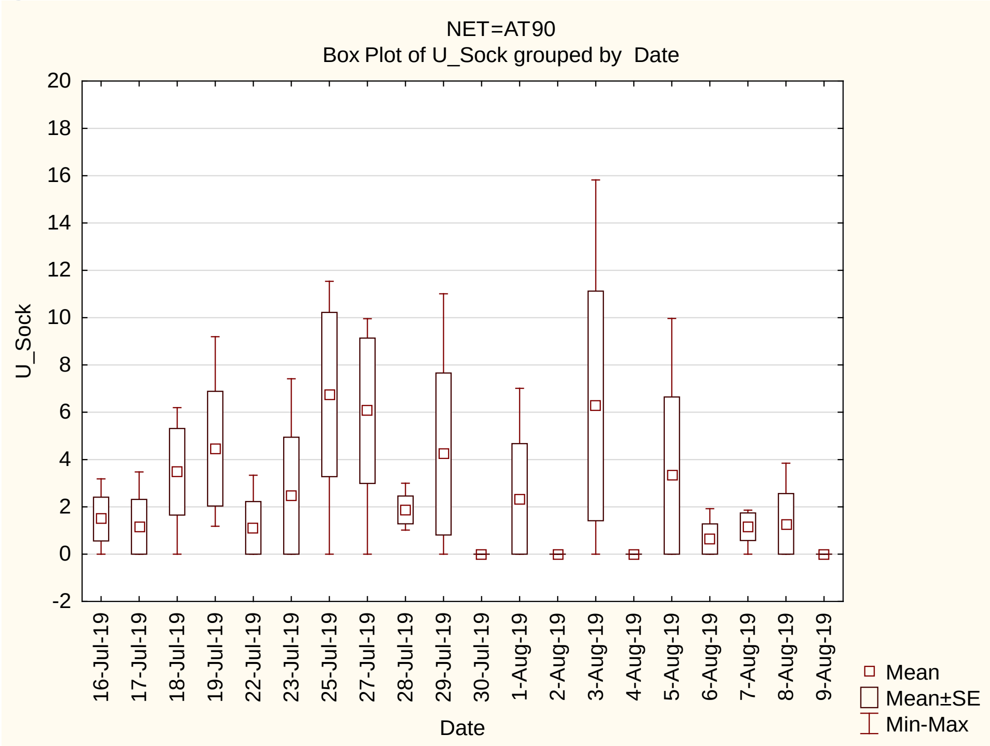
7. Tables

TABLE 1. SUMMARY OF DAILY SOCKEYE CPUES BY NET TYPE WHEN PAIRED SETS WERE CONDUCTED DURING THE 2019 SEASON. CPUES OF 0 REMOVED FROM RIGHTMOST COLUMN OF AT90/MS60 RATIOS.

Date	AT90	MS60	AT90/MS60
16-Jul-19	1.408	1.118	1.2596
17-Jul-19	2.683	2.025	1.3244
18-Jul-19	2.878	4.671	0.6163
19-Jul-19	4.733	4.175	1.1336
22-Jul-19	0.601	0.428	1.4041
23-Jul-19	1.792	0.862	2.0777
25-Jul-19	5.943	7.654	0.7764
27-Jul-19	3.757	3.258	1.1531
28-Jul-19	1.201	1.314	0.9138
29-Jul-19	3.622	1.353	2.6776
30-Jul-19	0.000	4.527	0.0000
1-Aug-19	1.728	2.481	0.6964
2-Aug-19	0.000	0.437	0.0000
3-Aug-19	4.053	6.633	0.6110
4-Aug-19	0.000	0.000	
5-Aug-19	1.685	1.248	1.3502
6-Aug-19	0.290	0.426	0.6818
7-Aug-19	0.848	1.253	0.6764
8-Aug-19	1.426	0.425	3.3577
9-Aug-19	0.858	6.961	0.1232
Mean	1.975	2.563	
Mean AT90/MS60	0.771		1.097

8. Figures



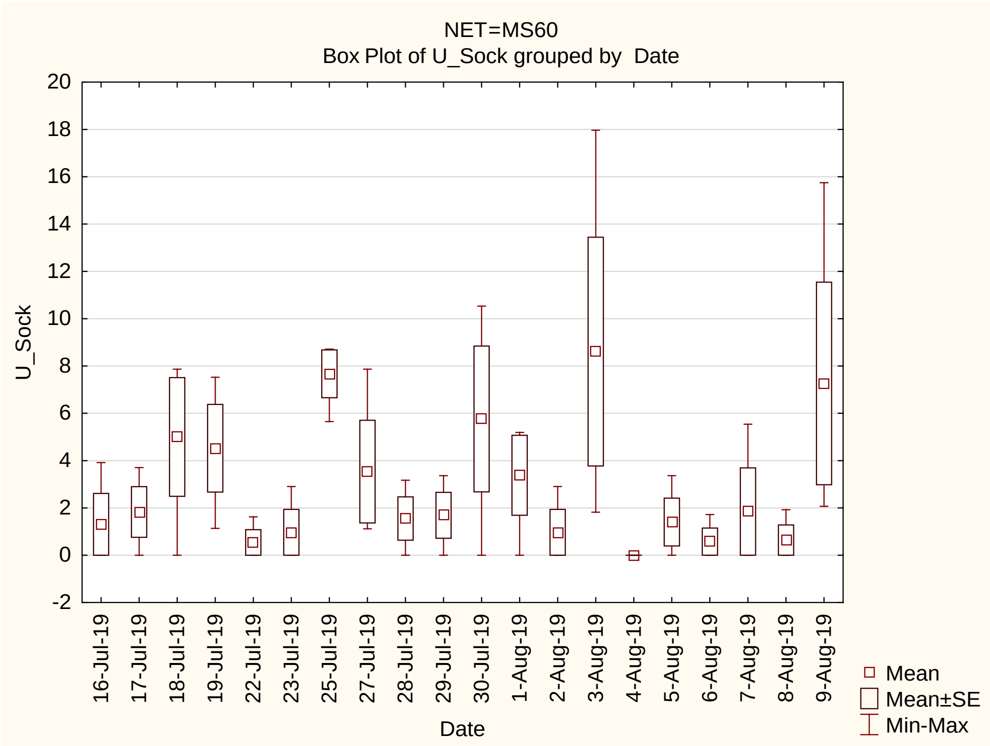
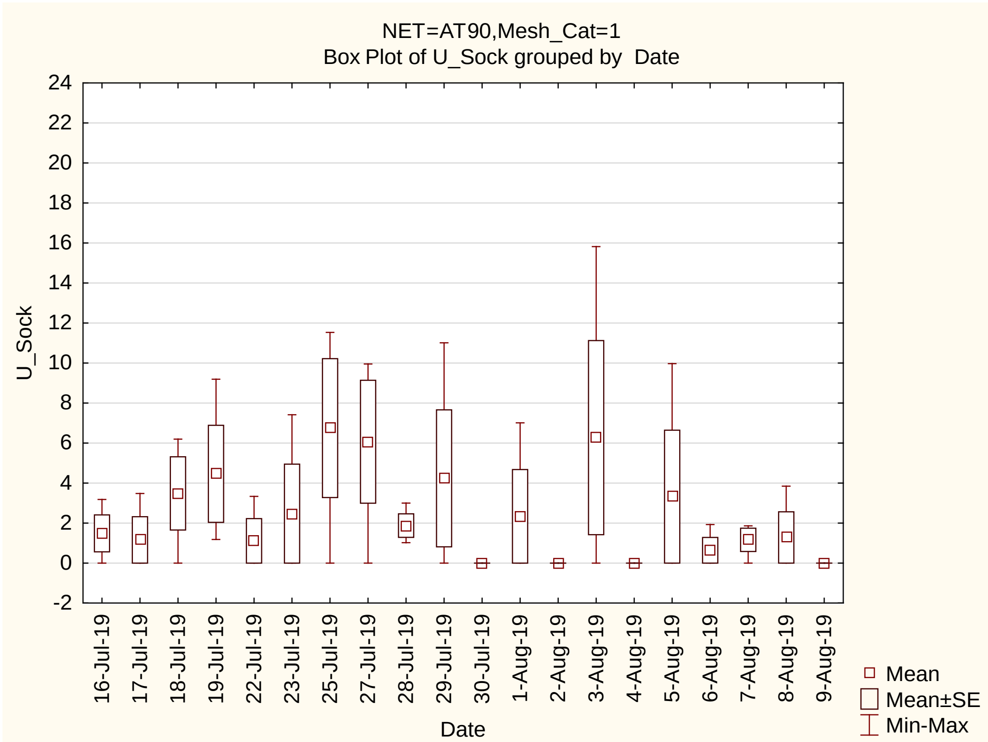


FIGURE 1. SOCKEYE CPUE BY NET TYPE, SURFACE PANEL ONLY, FOR PAIRED FISHING DATES.



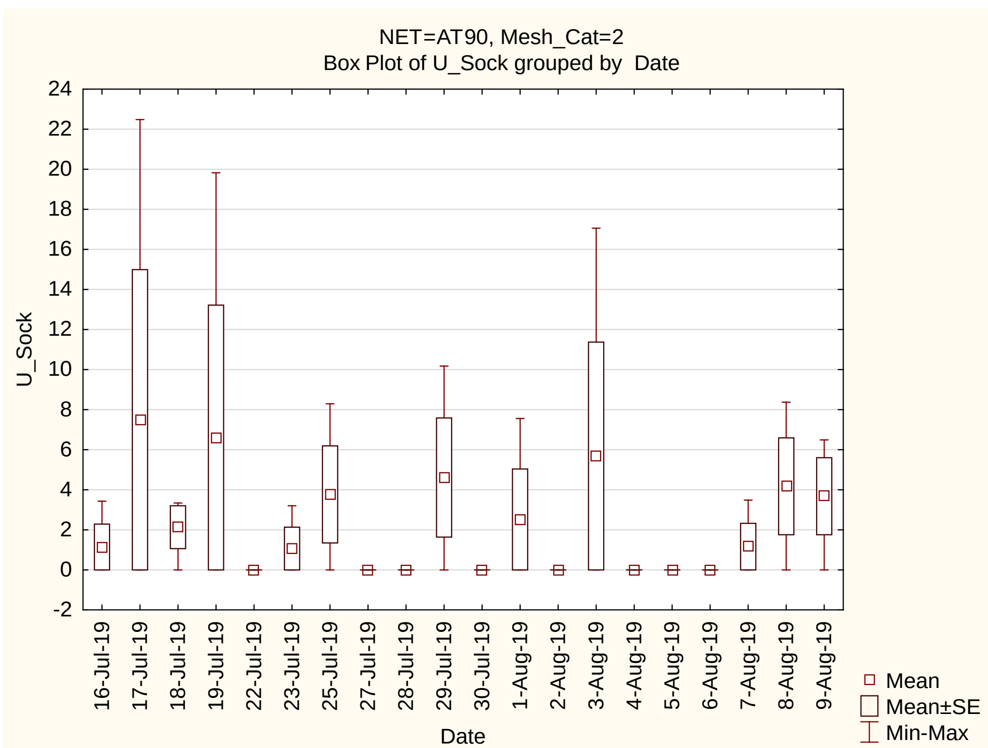


FIGURE 2. SOCKEYE CPUE, AT90 NET, SURFACE AND LOWER MESHES.

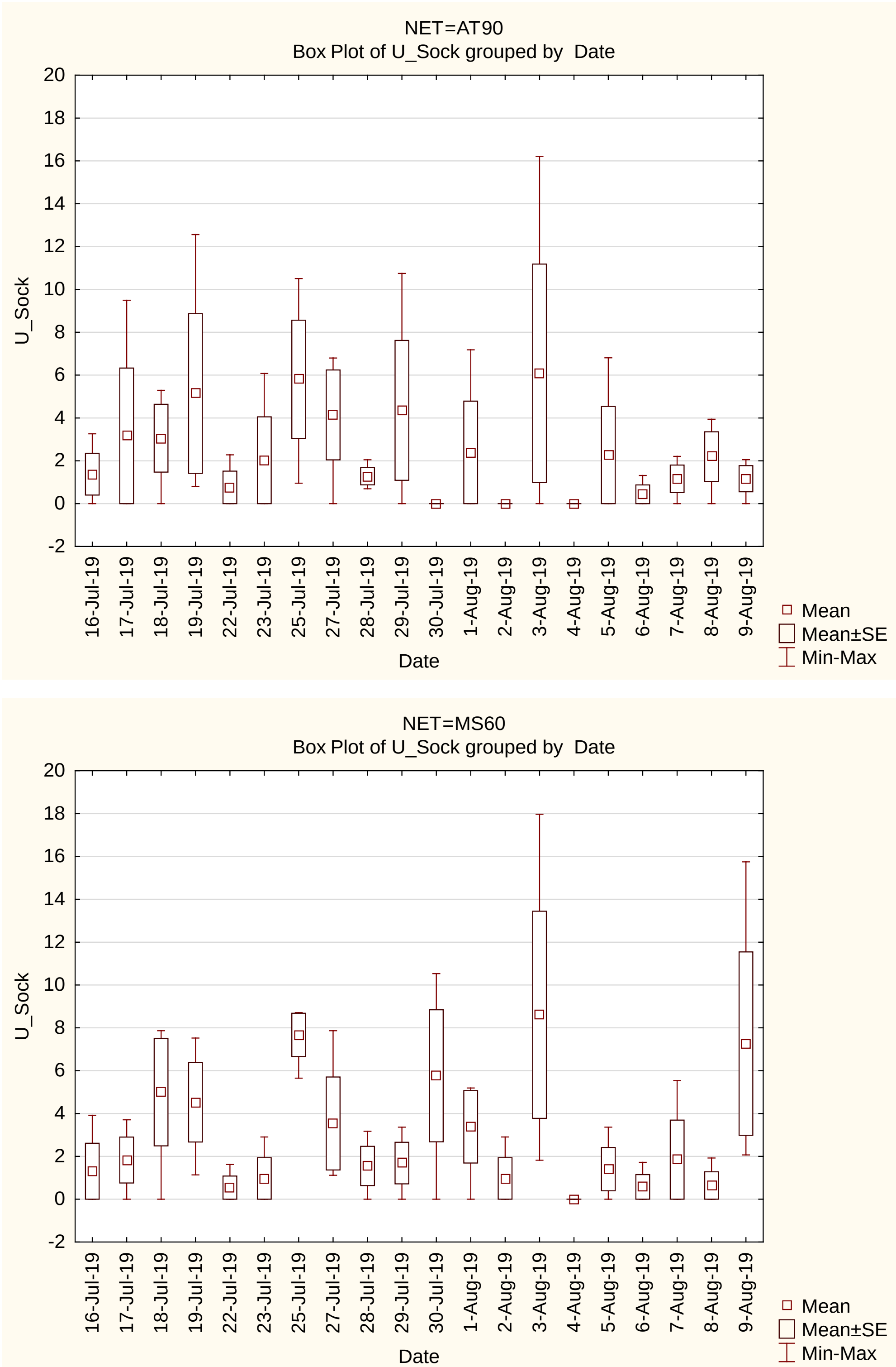


Figure 3. Sockeye CPUE of paired sets for the AT90 and MS60 nets. The AT90 net CPUE computed from catch and effort for surface and lower meshes combined.

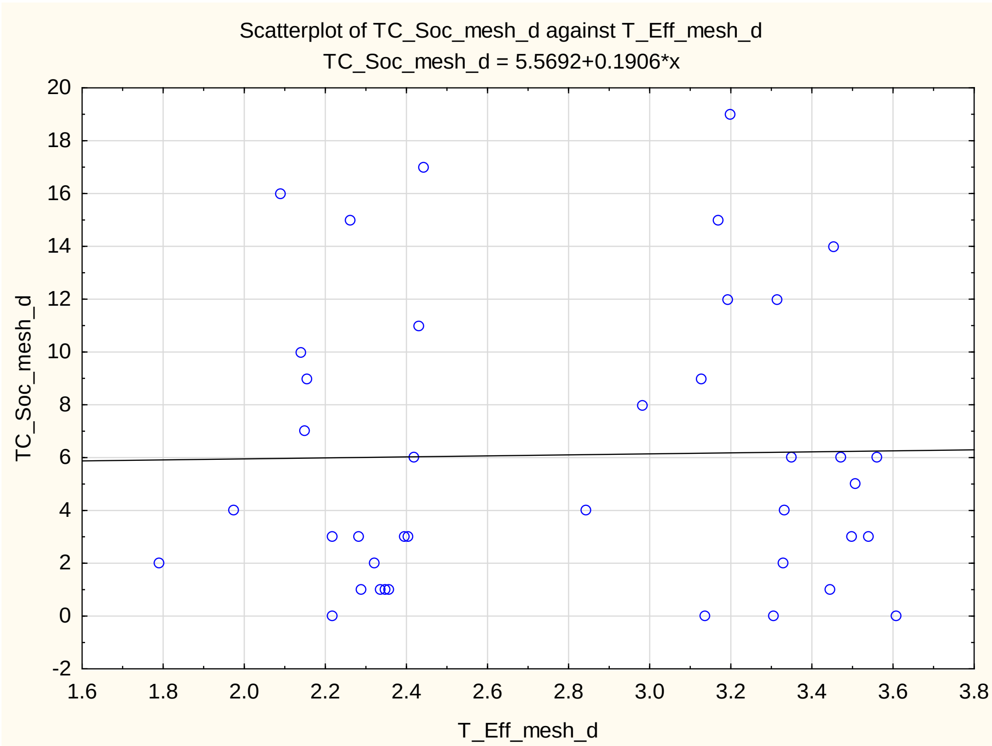


FIGURE 4. TOTAL SOCKEYE CATCH VERSUS TOTAL FISHING EFFORT (3 NIGHT SETS POOLED) FOR PAIRED SETS, WITHOUT DISTINCTION BY NET TYPE.

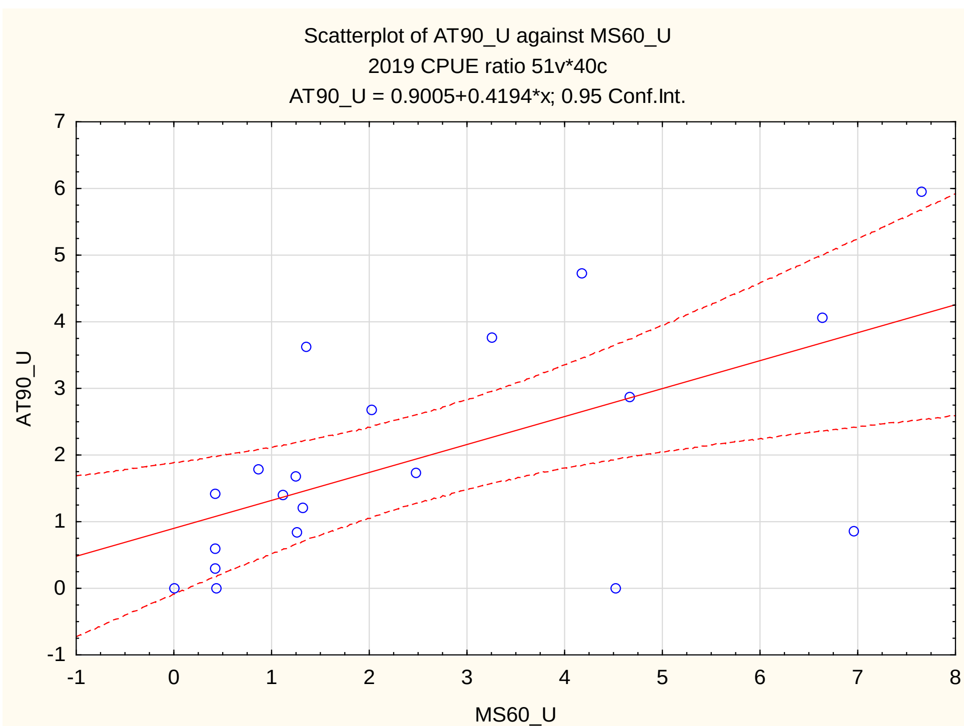


FIGURE 5. LINEAR RELATION OF DAILY SOCKEYE CPUE FOR AT90 VERSUS MS60 NETS FOR PAIRED SETS. NO EFFORTS MADE TO REMOVE POSSIBLE OUTLIERS. 95% CONFIDENCE REGRESSION BANDS DISPLAYED FOR VISUAL REFERENCE PURPOSES ONLY.

9. Appendix 1

Symbols and notation

b	generic label denoting the a linear regression coefficient (form y=*a*+*b*x)
d	gear index for mesh depth, 1 (surface: 0-60 mesh) or 2 (deep: 61-90 mesh)
g	an index for a fishing group operating in a given location (max=G)
h	net deployment time for a net or a portion of (in hours)
n	variable denotes a set number in a given period (max=*N*)
m	mesh type of the gillnet used (m=1 for Multi-strand, m=2 for Alaska twist)
p	index for a net fishing period (range 1-3: deployment, totally soaked, retrieval)
w	a week number(max = *W*)
C_n	total catch (in pieces), set *n*
E	fishing effort given net area only
E'	adjusted fishing effort using soak times for 3 net portions (in net area·hours)
$\bar{E}$	average fishing effort for a given stratum
$\bar{U}$	average CPUE
U_n	CPUE for set *n*
U	CPUE for a stratum
CPUE	Catch per unit effort

CPUE estimators

The CPUE is basically a ratio estimated using catch and effort records. There are no universally agreed upon method to estimate CPUE, since these are usually context-specific and account for variation in effort between sets, the level of correlation between catch and effort, and the weight given to various observations. CPUE estimators generally fall into several categories;

[1] Ratio estimator $$U = \frac{\sum_{n=1}^{N} C_n}{\sum_{n=1}^{N} E_n} = \frac{\bar{C}}{\bar{E}}$$

[2] Arithmetic estimator $$\overline{U} = \frac{\sum_{n=1}^{N} U_n}{N}$$

[3] Regression estimator $$\overline{U} = \frac{\sum_{n=1}^{N} (C_n - \bar{C})(E_n - \bar{E})}{\sum_{n=1}^{N} (E_n - \bar{E})^2}$$

[4] Geometric estimator $\bar{U} = \sqrt[N]{\prod_{n=1}^{N} U_n}$

Eq. 4 is rarely used unless there is a need to give equal weight to each CPUE index, or compare percent changes of variables on different scales. Eq. 3 is often considered as the best estimator to use when catch and effort are well correlated, and the relation between both variables is linear. The slope of linear regression of catch over effort is a measure of CPUE often equivalent to that obtained with Eq. 1. Using linear regressions allows for analyses of covariance (ANCOVAs) which can help identify outliers and statistically compare CPUE trends across strata.

Linear regression methods are not suitable in cases when the residual variance around the dependent variable (catch) is not well distributed and constant over the independent variable range (see Zar 1984, Cochran 1997). Also, gear catchability can change over time due to various factors such as fish abundance, gear saturation and vessel competition (see Hilborn and Walters 1992 for examples), in which case the relation between catch and effort is non-linear. When linear regression methods are not used, CPUE is often estimated with Eq. 1 or 2. Eq. 1 is the conventional estimator of a ratio (see Cochran 1997, p.30), good for a single set or a group of sets. In fisheries stock-assessment circles, it has been termed the 'ratio of mean estimator' (see Dauk and Schwarz 2000, Hoenig et al. 1997), or an 'unweighted index of density'. By contrast, Eq. 2 has been termed the 'mean of ratio estimator', or the weighted index of density. CPUE estimates from Eq.1 and Eq. 2 are not always identical. Some Monte Carlo simulation results show Eq. 1 is superior in some cases, but not in all. Dauk and Schwarz (2000) suggest that Eq. 2 may be more suitable for cases with incomplete records, missing data, when fishing periods differ (like set periods) and catch rates are not constant. Hoenig et al. (1997) noted Eq. 2 estimates tended to have a more unstable mean square error than Eq. 1 estimates, but if odd records are omitted (e.g., short fishing times), the estimates are very similar to those of Eq. 1.

In a recent study of the Fraser River gillnet fishery, Dauk and Schwarz (2000) opted for a modified Eq. 2 estimator to deal with cases involving gear saturation, where catch is not linearly related to effort. The authors proposed a new [complex] estimator to use for such cases. Gear saturation can be a problem when large runs are subject to test fishing (e.g., Fraser River sockeye runs), but this may not be obvious in all test fishing cases. In a prior comparison of AT90 and MS60 net performances for test fishing in the Skeena River, Labelle (2009) computed CPUEs by net type and short period (stratum) using Eq. 1, then estimated the mean CPUE for al strata using Eq. 2. A similar approach is used for this investigation.