Estimates of Diurnal Variation in Pacific Salmon Catch Rates Based on TINRO-Centre Trawl Survey Data

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To incorporate the survey data of the TINRO-Centre into a single dataset with the data from other scientific institutions, we have to take into account the time at which the sample was obtained. Also in order to estimate species abundance correctly we have to account for possible diel changes in the level of catches. The purpose of this study was to compare the CPUE values for daytime and nighttime trawling based on the original data collected at TINRO-Centre complex epipelagic surveys.

The original CPUE data collected by RV *TINRO*, RV *Professor Kaganovsky*, RV *Professor Kizevetter*, RV *Professor Levanidov*, and RV *Professor Soldatov* during the complex epipelagic surveys conducted in the Bering, Okhotsk and Japan Seas, and adjacent Pacific waters in 1991–2002 were analyzed for daytime and nighttime trawling. All of the epipelagic surveys that contained at least one of the investigated species and size-age groups (juveniles, immature, mature) were considered. Particular emphasis was given to data on Pacific salmon. It is well known (Birman 1985; Shuntov et al. 1993a, 1993b; Ogura 1994) that Pacific salmon reside mostly in the upper 30–50 meters layer, which is effectively fished by the trawls used by TINRO-Centre.

The average values of relative abundance were calculated separately for daytime and nighttime trawling in each area that was surveyed (Bering, Okhotsk and Japan Seas, Pacific Ocean). The ratios of these values (daytime CPUEs/nighttime CPUEs) were estimated as a fishing power correction factors for each species. A similar approach was employed previously when calculating fishing power differences for various trawls (Wilderbuer et al. 1998; von Szalay and Brown 2001).

The Shapiro-Wilk W test showed that CPUEs were not normally distributed. As a consequence, the nonparametric Mann-Whitney U test was used to test for differences in daytime and nighttime CPUEs. Similar statistical procedures were used previously in studies on diurnal variation in salmon catch obtained with drift gillnets (Eriksen and Marshall 1997).

Summary data on relative abundance estimates are presented in Table 1. Special emphasis was given to the results obtained for the first type of trawling selection (headrope depth during the trawling less or equal 25 m, depth at trawling location is more or equal 500 m and segregation of trawling into the daytime and nighttime trawling was done using the NOAA Calculator). The results obtained for the other three types of trawling selections were quite similar and provide additional support of our results.

During the comparison of nighttime and daytime trawling, it was found that, for most of the species studied, the abundance of salmon in the daytime trawling catch was higher compared with nighttime catches (Table 1). Also differences between nighttime and daytime abundance estimates were usually statistically significant (Table 2) for all the species studied (.0+ pink salmon, .0+ chum salmon, n.0+ sockeye salmon, n.0+ coho salmon and n.0+ masu salmon, mature pink and coho salmon) the CPUEs, except for immature Chinook salmon. In general, catches were lower at night than during the day. Also the investigated species appeared less frequently in catches at night than during the day. Some species were caught only during daytime and did not appear in night catches at several sampling sites.

The results obtained from the trawling classification based on mesopelagic fish species presence/absence (the second type of trawlings selection) also showed lower CPUEs at night (Table 1). The results obtained from the third and fourth types of trawling showed that the decrease in the CPUE of Pacific salmon and other investigated species at night was typical of the shelf areas as well (no restrictions on depth at trawling location were imposed during the selection of trawling).

We verified our assumption that the lower nighttime CPUEs values were observed for all the types of trawls used in the surveys. Significant differences were observed between daytime and nighttime catches when the number of sets performed by a given type of trawl was sufficiently large. For the trawl PT/TM 108/528, which was used most frequently, differences between daytime and nighttime catches were significant for most species (Table 2): juvenile pink salmon ($P = 0.03$), mature pink salmon ($P < 0.005$), n.0+ coho salmon ($P < 0.005$), mature coho salmon ($P < 0.005$), n.0+ sockeye salmon ($P = 0.02$). Also, an examination of Figures 1 and 2 showed a clear decrease of CPUEs at nighttime for all types of trawl.

Table 1. Ratios of species frequencies between daytime and nighttime trawling (%d/%n) and average values of fishing power correction factors for all the surveys (CPUEd/n).

Species	Size-age group	%d/%n $_{25\text{-}500}$	%d/%n $_{meso}$	CPUEd/n $_{25\text{-}500}$	CPUEd/n $_{meso}$	CPUEd/n $_{25\text{-}0}$	CPUEd/n $_{0\text{-}0}$
O. gorbuscha	.0+	1.0	1.0	1.3	1.6	1.4	1.6
	mature	1.1	1.0	1.7	1.8	2.2	2.2
O. keta	.0+	1.2	1.1	1.7	2.0	1.7	1.8
O. kisutch	n.0+	2.5	2.3	14.6	10.3	7.9	5.1
	mature	2.1	3.4	4.9	8.0	4.1	6.8
O. masou	n.0+	1.6	2.0	2.5	2.6	4.4	2.7
O. nerka	n.0+	2.4	2.7	5.8	4.0	6.7	5.7

Legend. %d/%n $_{25-500}$ - ratios of species frequencies between daytime and nighttime trawling (only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used, segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator); %d/%n$_{meso}$ - ratios of species frequencies between daytime and nighttime trawling (only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used; trawling that contained mesopelagic fish species were considered nighttime trawling and all others - daytime trawling); CPUEd/n$_{25-500}$ - average values of fishing power correction factors for all the surveys (only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used, segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator); CPUEd/n$_{meso}$ - only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used, trawling that contained mesopelagic fish species were considered nighttime trawling and all others - daytime trawling; CPUEd/n$_{25-0}$ - only trawling with trawl headrope depth < = 25 m were used (no restrictions on depth at trawling location), segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator; CPUEd/n$_{0-0}$ - only trawling with trawl headrope depth = 0 m were used (no restrictions on depth at trawling location), segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator.

Table 2. Mann-Whitney probabilities of equal day/night CPUEs for the surveys' joint datasets.

| Species	Size-age group	$P_{25\text{-}500}$	P_{meso}	$P_{25\text{-}0}$	$P_{0\text{-}0}$	P_{PT} ** 108/528	P_{PT} ** 80/396
O. gorbuscha	.0+	**0.01***	**0.00***	**0.02***	0.07	**0.03***	
	mature	**0.00***	**0.00***	**0.00***	**0.00***	**0.00***	**0.00***
O. keta	.0+	0.29	**0.01***	0.90	0.59		
O. kisutch	n.0+	**0.00***	0.28	**0.00***	**0.00***	**0.00***	
	mature	**0.00***	**0.00***	**0.00***	**0.00***	**0.00***	
O. masou	n.0+	0.55	0.28	**0.02***	0.08		
O. nerka	n.0+	0.09	**0.05***	**0.03***	0.08	**0.02***	
O. tshawytscha	immature	0.29	0.20	0.17	**0.02***		

Legend. P < 0.05 are marked by *; ** - only P < 0.05 are provided for these columns (only trawling done by the PT 108/528 and PT 80/396 trawls were used for comparisons); P_{25-500} - null-hypothesis probabilities (only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used, segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator); P_{meso} - only trawling with trawl headrope depth < = 25 m and depth at trawling location > = 500 m were used; trawling that contained mesopelagic fish species were considered nighttime trawling and all others - daytime trawling); P_{25-0} - only trawling with trawl headrope depth < = 25 m were used (no restrictions on depth at trawling location), segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator; P_{0-0} - only trawling with trawl headrope depth = 0 m were used (no restrictions on depth at trawling location), segregation of trawling into the daytime and nighttime trawling was done using theNOAA Calculator. P = 0.00 designates P < 0.005.

Evidently, the decrease of CPUEs at nighttime is due to the diurnal vertical migrations and behavior of the investigated species. Most likely, the nighttime migration of the investigated species brings them closer to the surface, which results in a higher avoidance of the trawl. We consider that during nighttime the maximum horizontal spread of trawl becomes more distant from the major concentrations of fish. This results in smaller CPUEs. Such explanation agrees quite well with the data from literature on diurnal vertical migrations of Pacific salmon. The decrease of CPUEs at nighttime can not be a result of species migration to the deeper water layers. It has been reported that the average depth used by Pacific salmon species was less for the nighttime period (Ogura and Ishida 1992; Ishida et al. 1998; Wada and Ueno 1999; Walker et al. 2000, 2001; Friedland et al. 2001). On the other hand, chinook salmon do not have any clear tendency to migrate closer to the sea surface during the nighttime and tend to be deeper than the other species (Ogura 1994; Radchenko and Glebov 1998; Murphy and Heard 2001).

The hydrodynamic plate that is mounted on the headrope and used during the epipelagic trawling at TINRO-Centre surveys creates turbidity at the surface. This may frighten the fish away. Also, the research vessel itself will frighten away fish that are located closer to the surface compared to fish that are deeper.

The results we obtained in this study suggest that there is significant diurnal variation in CPUEs of the investigated species. In the light of this we can conclude that it is necessary to introduce species-specific fishing power correction factors in order to make daytime and nighttime trawling comparable.

Fig. 1. Juvenile pink (1) and chum (2) salmon CPUEs (individuals per km^2) of daytime (vertical axis) and nighttime (horizontal axis) trawling plotted for every survey. Numbers designate the trawl type used for specific surveys (except for the most common trawl - PT 108/528).
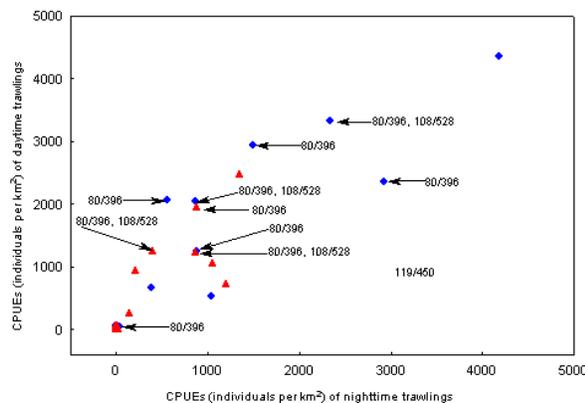
Fig. 2. Mature pink salmon CPUEs (individuals per km^2) of daytime (vertical axis) and nighttime (horizontal axis) trawling plotted for every survey. Numbers designate the trawl type used for specific surveys (except for the most common trawl - PT 108/528).
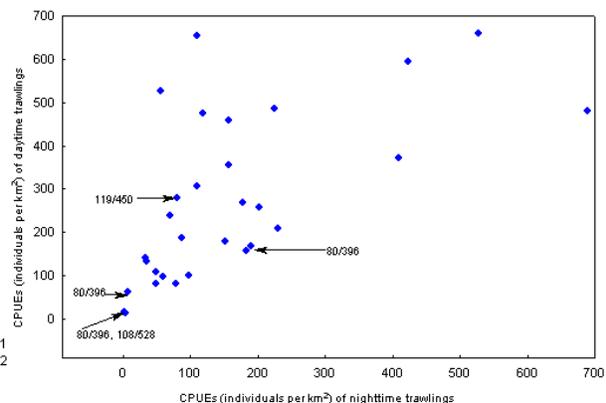
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