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Effect of unit of effort on analyses of observer coverage rates

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EFFECT OF UNIT OF EFFORT ON ANALYSES OF OBSERVER COVERAGE RATES

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INTRODUCTION

Lawson (2003, 2004, 2006) examined the relationship between coverage rates for longline and purse-seine observer programmes and the coefficient of variation of estimates of catch per unit effort (CPUE) for various species by sub-sampling observer data held by the SPC Oceanic Fisheries Programme. The analyses used catch per trip as the unit of CPUE on the basis that (i) the unit of CPUE, whether catch per trip or some other unit of effort, would not affect the results (and catch per trip was computationally convenient), and (ii) extrapolating the results from sub-sampling the population of observed trips to all trips in the fishery was reasonable, since the number of observed trips was sufficiently large. It will be shown below that both assumptions are incorrect.

COEFFICIENT OF VARIATION OF CPUE

Sampling theory provides an analytical method of determining the variance of CPUE estimates, which is computationally much more efficient than sub-sampling. For estimates of a ratio, such as CPUE, it can be shown (Cochran 1977) that the variance is approximated by

$$V(\hat{U}) \cong \frac{1-r}{n\overline{E}^2} \cdot \frac{\sum_i^N \left(c_i - Ue_i\right)^2}{N-1}, \tag{1}$$

where U and $\hat{U}$ are the true CPUE and estimated CPUE; $\overline{E}$ is the true average effort per replicate; c_i and e_i are the catch and effort for the i$^{\text{th}}$ observed replicate; N and n are the total number of replicates and the number of observed replicates; and r is the observer coverage rate, $\frac{n}{N}$.

Equation (1) can be simplified if the effort per replicate is always equal to 1, e.g., when the replicates are sets, the unit of effort is "set" and CPUE is in units of kilograms per set, or when replicates are individual hooks, the unit of effort is "hook" and CPUE is in units of kilograms per hook. In these cases, we have

$$V(\hat{U}) = \frac{1-r}{n} \cdot \frac{\sum_i^N \left(u_i - U\right)^2}{N-1}. \tag{2}$$

$$= \frac{V(U)}{n} \cdot (1-r). \tag{3}$$

That is, when the effort per replicate is equal to 1, equation (1) reduces to the variance of a mean, $\frac{V(U)}{n}$, with a finite population correction factor, $1-r$.

Using equation (2), the coefficient of variation of the estimate of CPUE can be written as

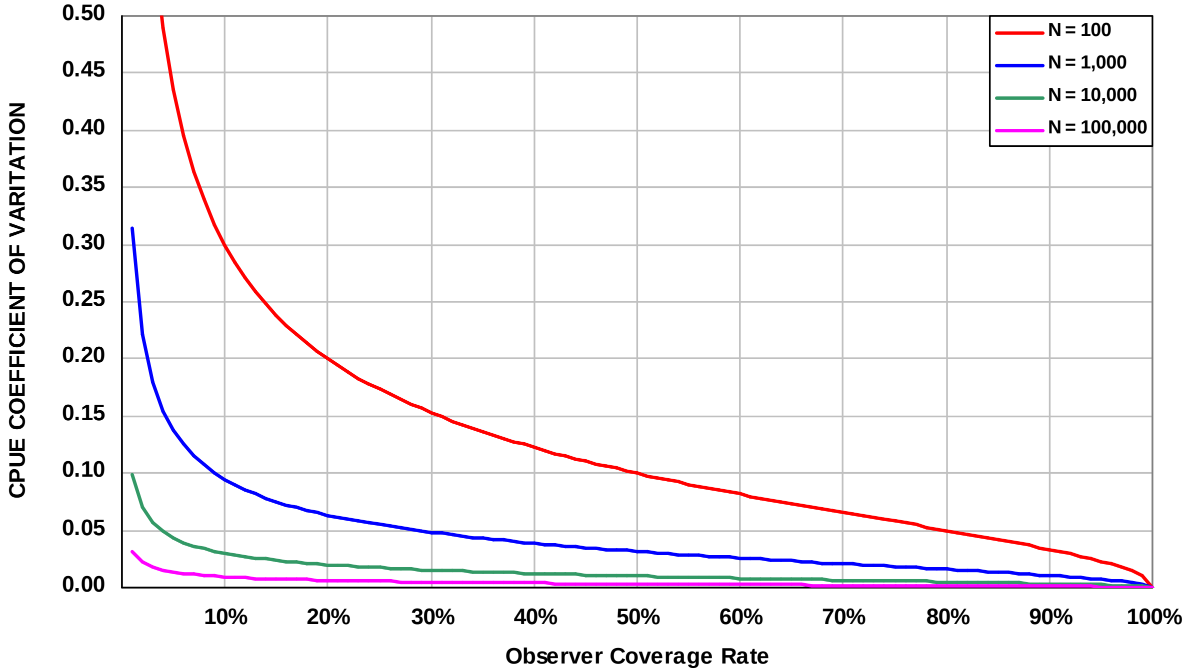
$$CV = \frac{\sqrt{V(\hat{U})}}{U} = \frac{\sqrt{\frac{1-r}{n} \cdot \frac{\sum_{i}^{N} \left(u_i - U\right)^2}{N-1}}}{U} . \tag{4}$$

$$= \sqrt{\frac{1}{n} - \frac{1}{N}} \cdot \frac{\sqrt{\frac{\sum_{i}^{N} \left(u_i - U\right)^2}{N-1}}}{U} . \tag{5}$$

The coefficient of variation of the estimate of CPUE thus depends on the number of observed units of effort and the total number of units of effort — the lefthand part of the formula — and the ratio of the standard deviation of CPUE to the true population CPUE — the righthand part of the formula. Equation (4) can be used in terms of any unit of effort, e.g., trip or longline set or longline hook or purse-seine day fished, so long as each replicate represents one unit of effort.

Figure 1 illustrates how relationship between the coefficient of variation and the observer coverage rate depends on the total number of effort units in the population; for illustrative purposes, the ratio of the standard deviation of CPUE to the true population CPUE on the righthand part of equation (5) has been set equal to 1. For all cases in Figure 1, the coefficients of variation decrease rapidly as the coverage rate increases, then it decreases slowly until reaching zero at a coverage rate of 100%. However, the general level of the coefficients of variation depend on the total number of effort units, with the level decreasing strongly as the number of effort units increases from 100 to 1,000 to 10,000, and then decreasing less strongly from 10,000 to 100,000.

Figure 1. Effect of total number of effort units on the relationship between the observer coverage rate and the CPUE coefficient of variation



FINITE POPULATION EFFECT ON PURSE SEINE

To illustrate the dependence of the relationship between the CPUE coefficient of variation and the observer coverage rate on the total number of units of effort, equation (5) was applied to the purse-seine fishery in the WCPFC Statistical Area. Two units of effort were considered: (i) trip and (ii) day fished or searched.

The model parameters for "trip" as the unit of effort, i.e. the standard devation of the catch per unit of effort — the numerator in the righthand part of Eq. (5) — and the true CPUE — the denominator of the righthand part of Eq. (5) — are presented for six species in Table 1. The catch rates vary from common (skipjack) to less common (rainbow runner) to increasingly rare.

Table 1. Average catch per trip (tonnes) and catch per trip standard deviation for six species caught by purse seine

Species	Average Catch Per Trip	Catch Per Trip Standard Deviation	Catch Per Trip Coef of Variation
Skipjack	500.435940	344.419750	0.69
Rainbow runner	2.842200	7.957390	2.80
Silky shark	0.521480	1.220540	2.34
Whale shark	0.426560	4.872180	11.42
Striped marlin	0.034500	0.161400	4.68
Great white shark	0.000050	0.001740	34.80

Figure 2 shows the relationship between the coefficient of variation of the estimate of CPUE and the observer coverage rate for the population of observed purse-seine trips, similar to what was presented in Lawson (2006) — that is, N in Eq. (5) was set to 525. As is typical in these figures, (i) the coefficient of variation of the estimate declines rapidly with increasing coverage up to a point and then decreases less rapidly with higher coverage, and (ii) the general level of the coefficient of variation of the estimate is strongly related to the catch rate, with higher coefficients of variation for lower catch rates.

Figure 2. Coefficient of variation of estimates of purse-seine CPUE (tonnes per trip), assuming 525 trips per annum

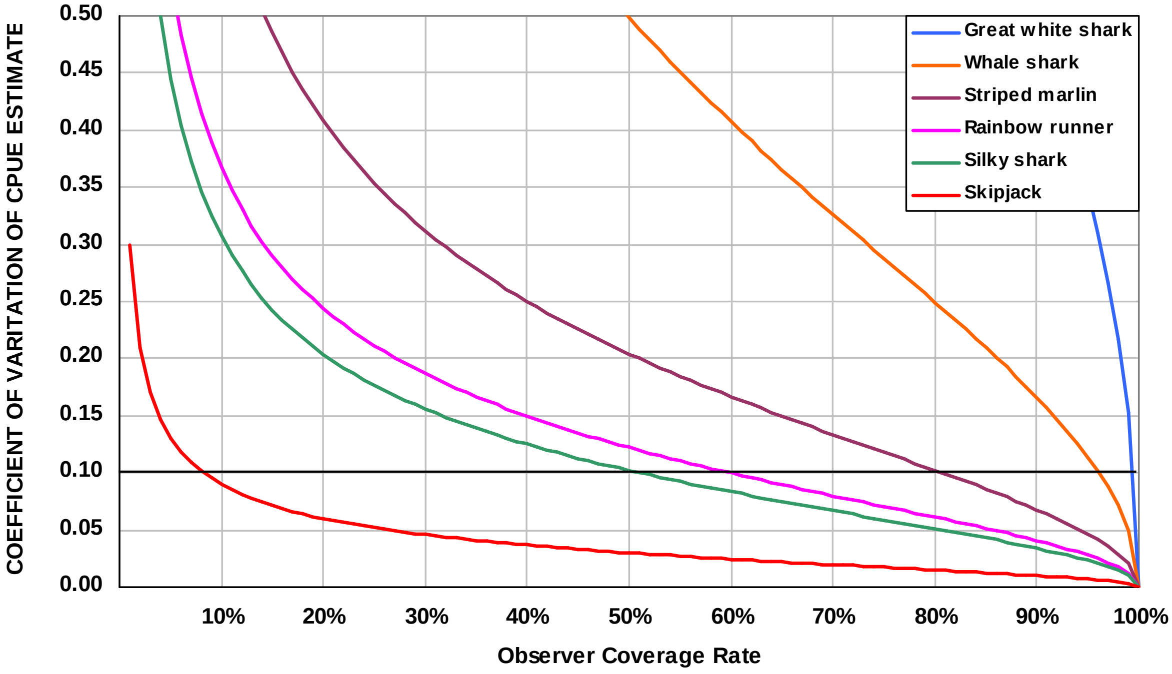
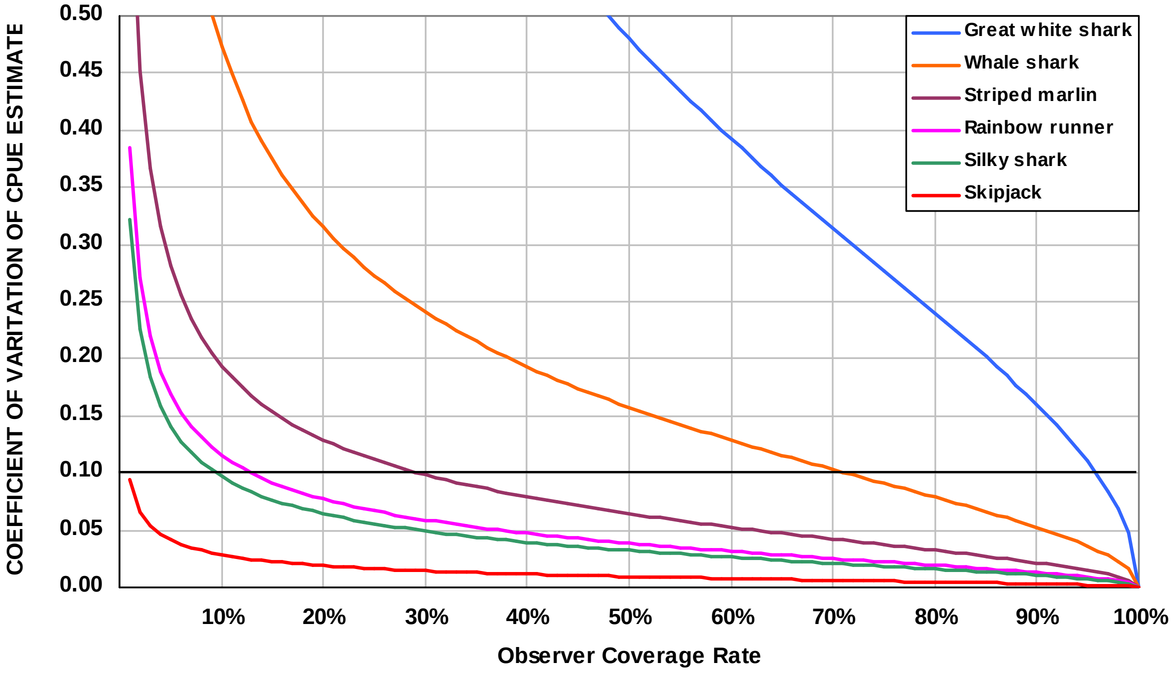


Figure 3 also shows the relationship between the coefficient of variation of the estimate of CPUE and the observer coverage rate; however, instead of defining the population to be "observed trips", which is analagous to what was done in the studies referred to in the introduction based on sub-sampling, the population is defined to be the average annual number of all purse-seine trips, whether observed or not observed, taken from 2002 to 2006 — that is, N in Eq. (5) was set to 5,250, a number ten times greater than the total number of observed trips. As can be seen, the shape of the curves are similar to those in Figure 2; however, the level of coefficients of variation are lower than in Figure 2. Hence, the sub-sampling of observed trips, as in Lawson (2006), results in a finite population effect that over-estimates the coefficient of variation of the estimate of CPUE.

Figure 3. Coefficient of variation of estimates of purse-seine CPUE (tonnes per trip), assuming 5,250 trips per annum



EFFECT OF UNITS OF EFFORT ON PURSE SEINE

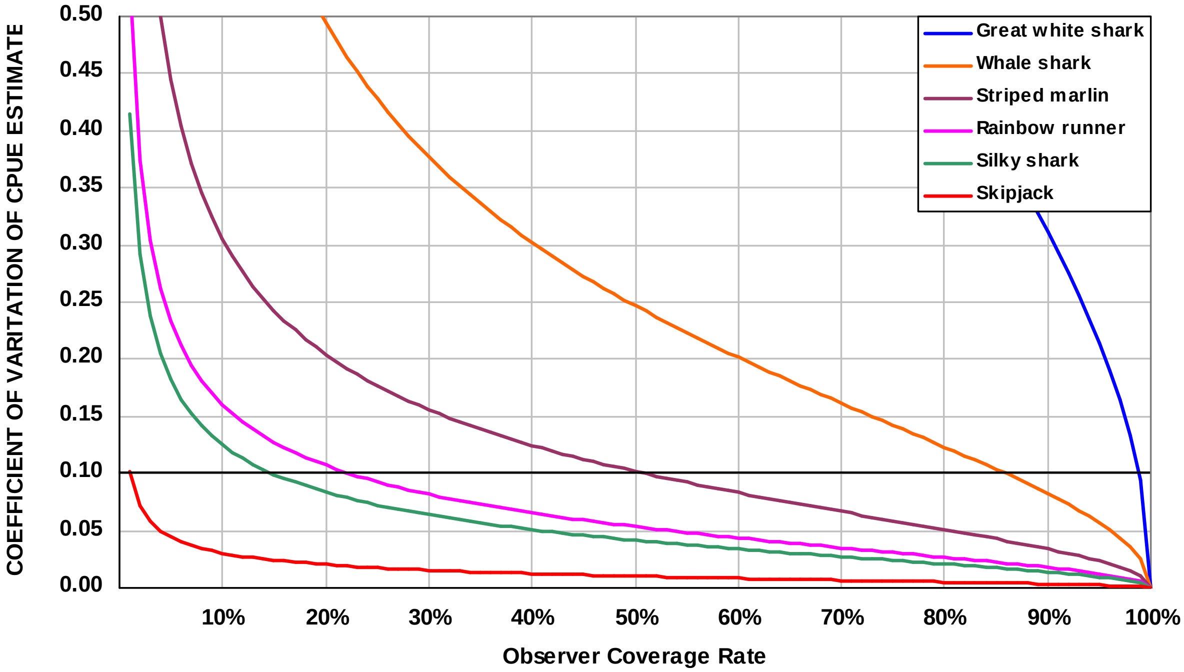
To examine the effect of the unit of effort, Figure 3 was replicated with "days fished or searched" as the unit of effort. The model parameters for "days fished" as the unit of effort are presented for the same six species in Table 2.

Table 2. Average, standard deviation and coefficient of variation of catch per day (tonnes) for six species caught by purse seine

Species	Average Catch Per Day	Catch Per Day Standard Deviation	Catch Per Day Coef of Variation
Skipjack	15.555798	33.242162	2.14
Rainbow runner	0.088966	0.999620	11.24
Silky shark	0.016231	0.142133	8.76
Whale shark	0.013206	0.683720	51.77
Striped marlin	0.001073	0.022959	21.40
Great white shark	0.000002	0.000307	195.74

Figure 4 shows the relationship between the CPUE coefficient of variation and the observer coverage rate, with "days fished or searched" as the unit of effort — N in Eq. (5) was set to 44,000, which is approximately the average annual number of days fished or searched in the WCPFC Statistical Area (excluding the domestic fisheries of Indonesia and the Philippines) from 2002 to 2006. The general levels of the coefficient of variation are somewhat higher in Figure 4, compared to Figure 3, though still relatively close.

Figure 4. Coefficient of variation of estimates of purse-seine CPUE (tonnes per day fished or searched), assuming 44,000 days fished per annum



EFFECT OF UNITS OF EFFORT ON OFFSHORE LONGLINERS TARGETING ALBACORE

The relationship between the CPUE coefficient of variation and the observer coverage rate was examined for (a) offshore longliners in sub-tropical waters targeting albacore and (b) offshore longliners in tropical waters targeting yellowfin and bigeye; for each longline sector, both “set” and “hook” were used as the units of effort.

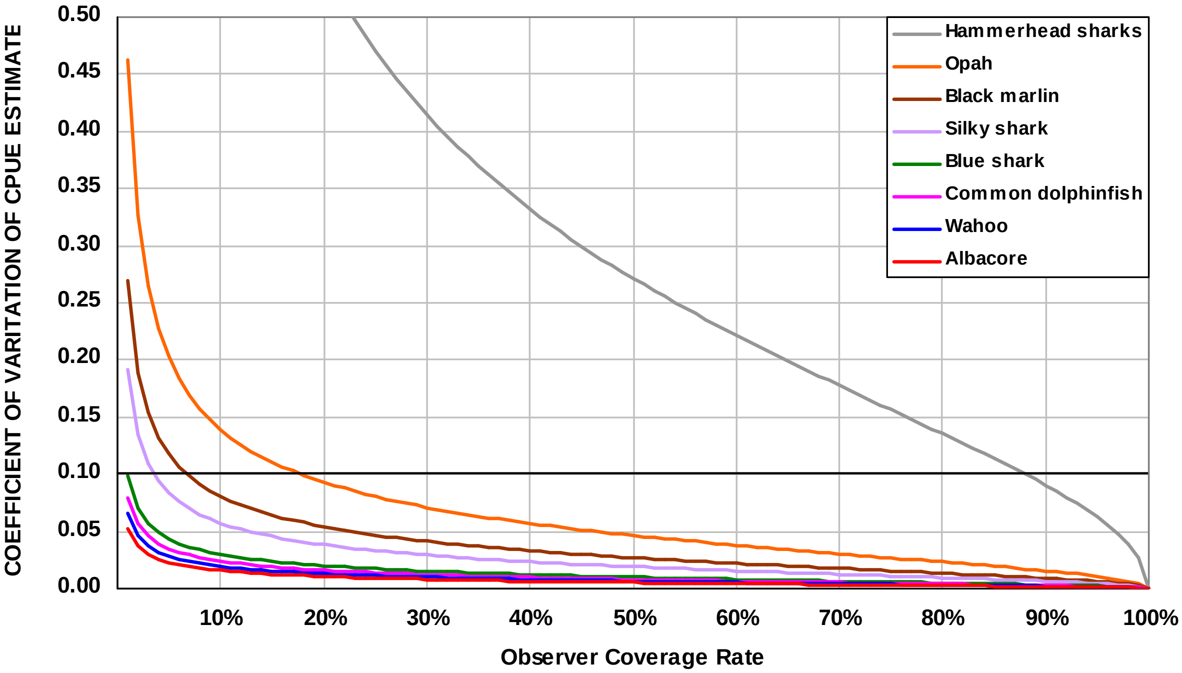
Fleets of offshore longliners targeting albacore include those of American Samoa, Cook Islands, Fiji, French Polynesia, New Caledonia, Samoa and Tonga. These fleets combined set an average of 96 million hooks per annum during 2002–2006; with an average number of hooks per set of 2,248, these fleets set an average of about 42,700 sets per annum. The model parameters for eight species and species groups, with “set” as the unit of effort, are presented in Table 3.

Table 3. Average, standard deviation and coefficient of variation of catch per set (kilograms) for eight species caught by offshore longliners targeting albacore

Species	Average Catch Per Set	Catch Per Set Standard Deviation	Catch Per Set Coef of Variation
Albacore	388.610175	422.819790	1.09
Blue shark	58.144038	120.024745	2.06
Wahoo	25.921463	35.070329	1.35
Common dolphinfish	15.693800	26.105848	1.66
Silky shark	10.770429	42.724598	3.97
Black marlin	5.402226	30.151938	5.58
Opah	3.975835	38.245965	9.62
Hammerhead sharks	0.049921	2.799557	56.08

Figure 5 shows the relationship between the CPUE coefficient of variation and the observer coverage rate for offshore longliners targeting albacore, with “set” as the unit of effort. The levels of the coefficients of variation are generally lower than for purse seine, which, given that the total number of effort units is roughly the same as for purse-seine days fished, reflects the lower level of variation in the longline catch per set. For offshore longliners targeting albacore, the average ratio of variation in the catch per set to the average catch per set for the eight species shown in Figure 5 is 10.2; for purse seine, the average ratio in variation in the catch per day to the average catch per day for the six species shown in Figure 4 is 48.5.

Figure 5. Coefficient of variation of estimates of CPUE (kilograms per set) for offshore longliners targeting albacore, assuming 42,700 sets per annum



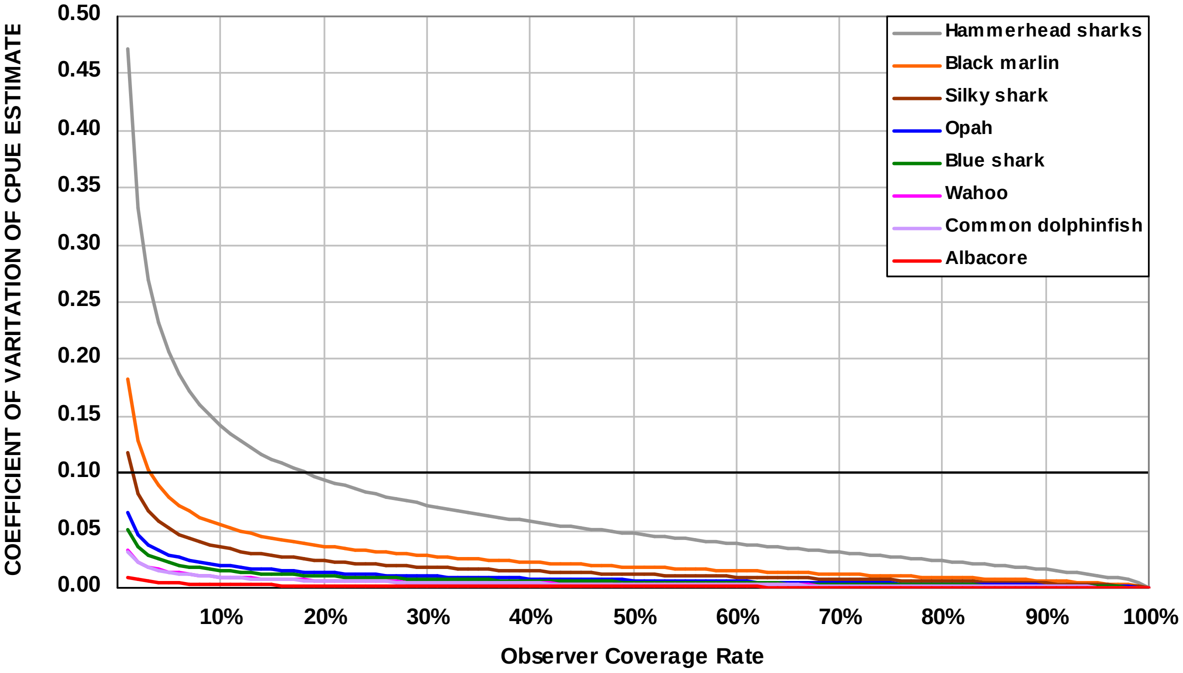
To examine the effect of the unit of effort, Figure 5 was replicated with "hook" as the unit of effort. The model parameters for the eight species and species groups, with "hook" as the unit of effort, are presented in Table 4.

Table 4. Average, standard deviation and coefficient of variation of catch per hook (kilograms) for eight species caught by offshore longliners targeting albacore

Species	Average Catch Per Hook	Catch Per Hook Standard Deviation	Catch Per Hook Coef of Variation
Albacore	0.189573	1.802998	9.51
Blue shark	0.026862	1.340401	49.90
Opah	0.017743	1.155452	65.12
Wahoo	0.012168	0.386554	31.77
Common dolphinfish	0.007313	0.225801	30.88
Silky shark	0.004837	0.562262	116.23
Black marlin	0.002624	0.470405	179.25
Hammerhead sharks	0.000402	0.186421	464.28

Figure 6 shows the relationship between the CPUE coefficient of variation and the observer coverage rate for offshore longliners targeting albacore, with “hook” as the unit of effort. The levels of the coefficients of variation are generally lower than with “set” as the unit of effort, except for extremely rare species, e.g., hammerhead sharks, for which the level of coefficient of variation is the same. The lower levels are related to the large population of effort units, i.e., 96 million hooks vs 42,700 sets. With “hook” as the unit of effort, 1% observer coverage amounts to 960 thousand hooks, which implies that $\sqrt{\frac{1}{n}}$ in equation (5) is equal to 0.1%; hence the absolute number of observed effort units, even at a low level of coverage, has a huge effect on the coefficient of variation. The effect of the absolute number of observed effort units is examined further below.

Figure 6. Coefficient of variation of estimates of CPUE (kilograms per hook) for offshore longliners targeting albacore, assuming 96 million hooks per annum



EFFECT OF UNITS OF EFFORT ON OFFSHORE LONGLINERS TARGETING YELOWFIN AND BIGEYE

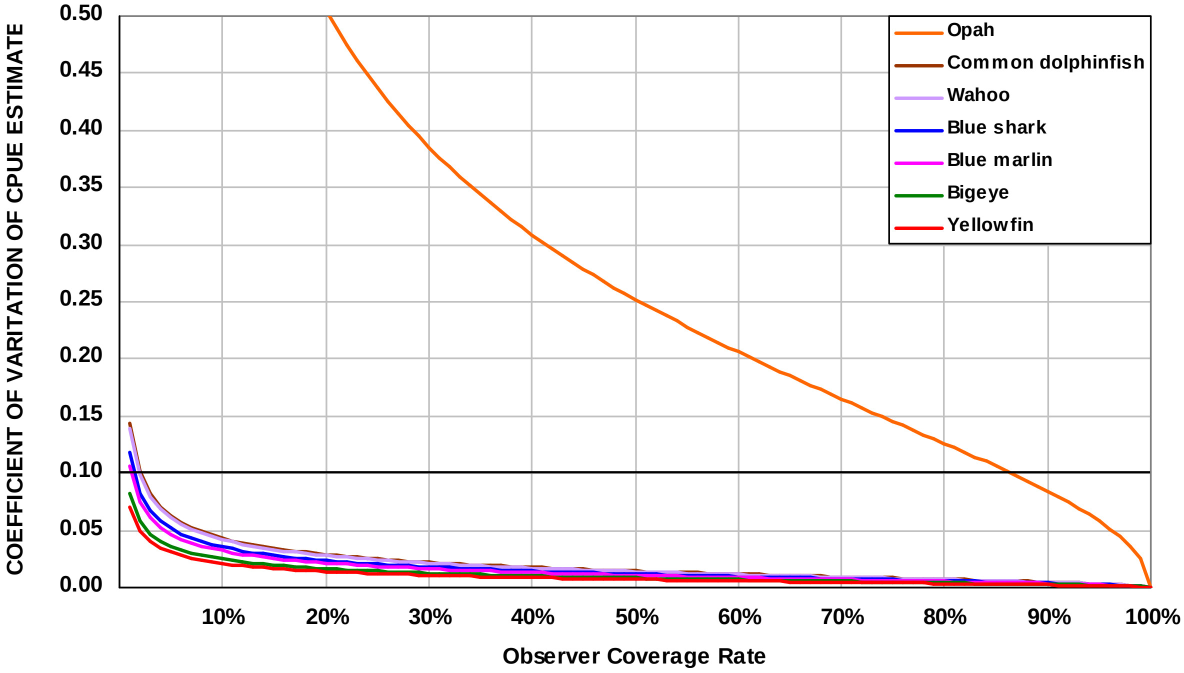
Fleets of offshore longliners targeting yellowfin and bigeye include those of China, Federated States of Micronesia, Japan, Papua New Guinea and Chinese Taipei. These fleets combined set an average of 60 million hooks per annum during 2002–2006; with an average number of hooks per set of 1,313, these fleets set an average of about 45,800 sets per annum. The model parameters for seven species, with “set” as the unit of effort, are presented in Table 5.

Table 5. Average, standard deviation and coefficient of variation of catch per set (kilograms) for seven species caught by offshore longliners targeting yellowfin and bigeye

Species	Average Catch Per Set	Catch Per Set Standard Deviation	Catch Per Set Coef of Variation
Yellowfin	208.525034	316.182945	1.52
Bigeye	128.798011	228.013218	1.77
Blue shark	50.415638	127.948478	2.54
Blue marlin	37.737654	86.782175	2.30
Wahoo	5.356310	16.069134	3.00
Common dolphinfish	1.993827	6.172642	3.10
Opah	0.019204	1.037037	54.00

Figure 7 shows the relationship between the CPUE coefficient of variation and the observer coverage rate for offshore longliners targeting yellowfin and bigeye, with “set” as the unit of effort. The levels of the coefficients of variation are even lower than for offshore longliners targeting albacore with “set” as the unit of effort, which, again, reflects the lower level of variation in the catch per set. For offshore longliners targeting yellowfin and bigeye, the ratio of variation in the catch per set to the average catch per set for the seven species shown in Figure 6 is 9.7.

Figure 7. Coefficient of variation of estimates of CPUE (kilograms per set) for offshore longliners targeting yellowfin and bigeye, assuming 45,800 sets per annum



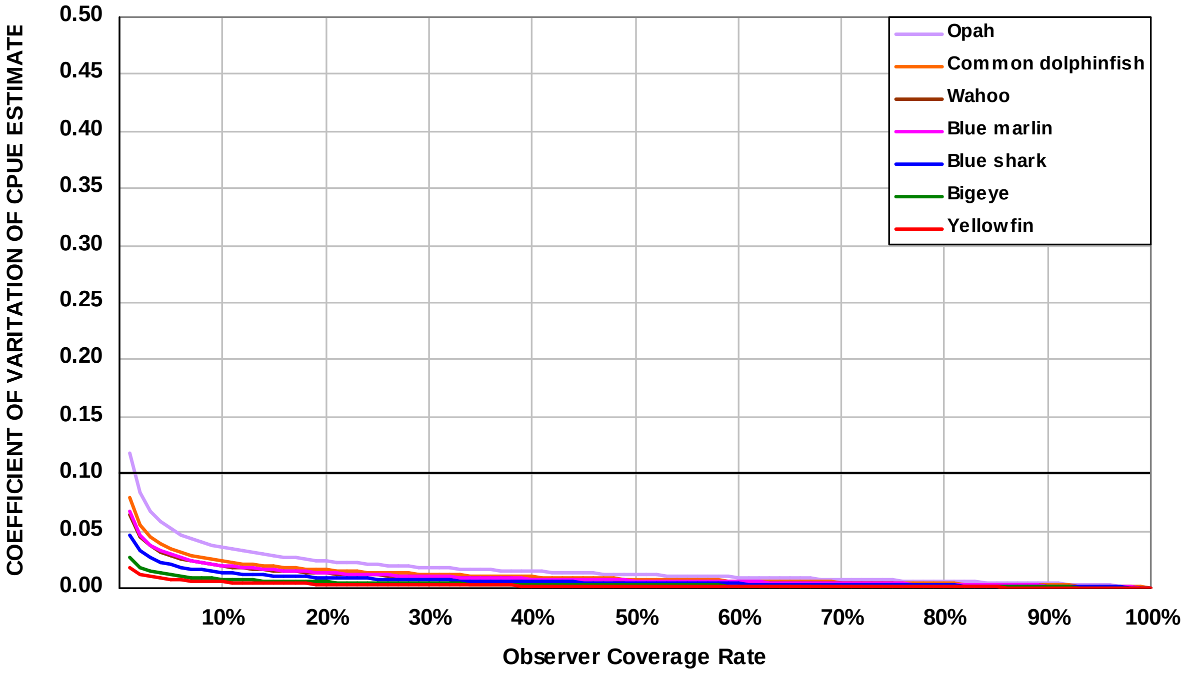
To examine the effect of the unit of effort, Figure 7 was replicated with “hook” as the unit of effort. The model parameters for the seven species, with “hook” as the unit of effort, are presented in Table 6.

Table 6. Average, standard deviation and coefficient of variation of catch per hook (kilograms) for seven species caught by offshore longliners targeting yellowfin and bigeye

Species	Average Catch Per Hook	Catch Per Hook Standard Deviation	Catch Per Hook Coef of Variation
Yellowfin	0.168347	2.332606	13.86
Bigeye	0.106526	2.184934	20.51
Blue shark	0.042111	1.519308	36.08
Blue marlin	0.029669	1.543957	52.04
Opah	0.007595	0.701400	92.35
Wahoo	0.004424	0.223177	50.45
Common dolphinfish	0.001648	0.101650	61.69

Figure 8 shows the relationship between the CPUE coefficient of variation and the observer coverage rate for offshore longliners targeting yellowfin and bigeye, with “hook” as the unit of effort. As for offshore longliners targeting albacore, the levels of the coefficients of variation are generally lower than with “set” as the unit of effort, except for extremely rare species, e.g., hammerhead sharks, for which the level of coefficient of variation is the same. Again, the lower levels are related to the large population of effort units, i.e., 60 million hooks vs 45,800 sets.

Figure 8. Coefficient of variation of estimates of CPUE (kilograms per hook) for offshore longliners targeting yellowfin and bigeye, assuming 60 million hooks per annum



EFFECT OF COVARIATES

Including covariates in models of CPUE, such as “trip” for purse seine and “trip” and “set” for longline, should explain some of the variation in CPUE and thereby reduce the observer coverage rate required for a given level of reliability of estimates of CPUE. For example, Table 7 and 8 present the results of an analysis of variance of catch per hook for offshore longliners targeting albacore, and yellowfin and bigeye, respectively, with the trip and the set corresponding to each hook as model parameters.

Table 7. Effect of including trips and sets to explain variation in the catch per hook (kilograms) for eight species caught by offshore longliners targeting albacore

Species	Catch Per Hook Standard Deviation	F Values		Residual Standard Deviation
		Trips	Sets	
Albacore	1.802998	164.87	32.45	1.784032
Blue shark	1.340401	24.91	5.17	1.338442
Opah	1.155452	13.55	3.29	1.154539
Wahoo	0.386554	17.63	6.61	0.385927
Common dolphinfish	0.225801	27.51	10.78	0.225176
Silky shark	0.562262	11.78	3.01	0.561874
Black marlin	0.470405	17.82	4.94	0.469816
Hammerhead sharks	0.186421	33.01	6.79	0.186048

Table 8. Effect of including trips and sets to explain variation in the catch per hook (kilograms) for seven species caught by offshore longliners targeting yellowfin and bigeye

Species	Catch Per Hook Standard Deviation	F Values		Residual Standard Deviation
		Trips	Sets	
Yellowfin	2.332606	99.03	17.11	2.312092
Bigeye	2.184934	43.74	6.98	2.177316
Blue shark	1.519308	58.47	9.18	1.512120
Blue marlin	1.543957	15.46	9.58	1.538456
Opah	0.701400	6.49	2.04	0.701016
Wahoo	0.223177	17.17	2.98	0.222905
Common dolphinfish	0.101650	15.58	4.20	0.101486

Both trips and sets can be considered statistically significant according to the F values in Tables 7 and 8 (ignoring for the moment the departure from normality and lack of independence of these data). However, the value of the residual standard deviation is only slightly lower than the catch per hook standard deviation, and substituting the residual standard deviation in equation (5) does not change the relationship between coverage rate and the coefficient of variation of estimates of CPUE.

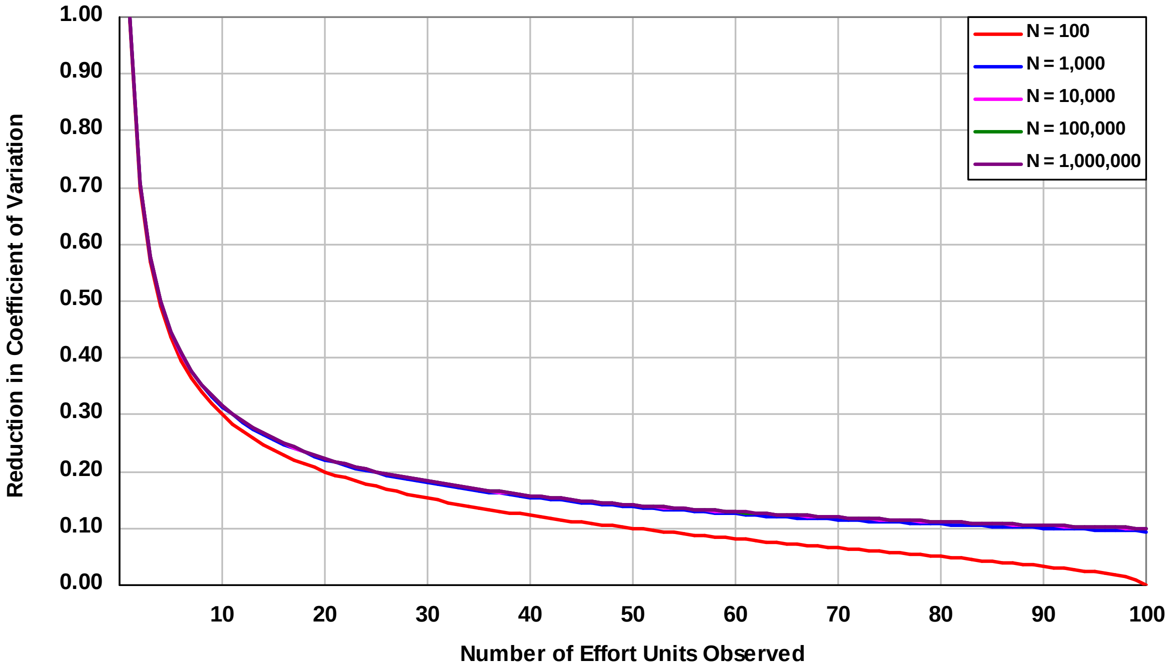
Other covariates — such as year, month, latitude, longitude, hooks between floats and oceanographic variables — could perhaps be examined, but the results for “trip” and “set” suggest that they would probably not affect the relationship between coverage rate and the coefficient of variation of estimates of CPUE.

ABSOLUTE NUMBER OF OBSERVED EFFORT UNITS

According to equation (5), the coefficient of variation will decrease in proportion to the square root of the inverse of the absolute number of effort units observed (the lefthand part of equation 5), regardless of the magnitude of the ratio of the variation in the catch to the true CPUE (the righthand part of equation 5). Figure 7 shows this relationship for various magnitudes of the total population of effort units, ranging from 100 to 1,000,000. The absolute number of observed effort units in Figure 7 ranges from 1 to 100.

For a total population of 100 effort units, it can be seen in Figure 7 that the coefficient of variation is reduced to zero as the absolute number of effort units observed is increased to 100 — when the population of effort units is only 100, coverage is complete when the number of observed effort units is 100. However, when the order of magnitude of the population of effort units is three or greater and when the number of observed effort units is 100, $\frac{1}{N}$ in $\sqrt{\frac{1}{n}-\frac{1}{N}}$ tends to zero and $\sqrt{\frac{1}{n}}$ is equal to 10%.

Figure 9. Reduction in coeficient of variation based on absolute number of effort units observed



While the CPUE coefficient of variation can be reduced by 90% with 100 observed effort units for all species and for any unit of effort, the absolute level of the coefficient of variation will depend on the ratio of the variation in the catch to the true CPUE (the righthand part of equation 5), which, in turn, depends on the unit of effort. The ratios for each of the species examined above are given in Tables 1–6. For example, for blue shark caught by offshore longliners targeting albacore, the coefficient of variation will be reduced from 2.06 (Table 3) for one observed set to 0.21 for 100 observed sets. While a coefficient of variation of 21% may be considered large, it is still a major improvement for only 100 observed sets.

Obviously, the situation is different when "hook" is the unit of effort, since the ratios of the variation in the catch to the true CPUE are much greater. For example, for blue shark caught by offshore longliners targeting albacore, the coefficient of variation will be reduced from 51.58 (Table 4) for one observed hook to 5.16 for 100 observed hooks. While the coefficient of variation has been reduced by 90%, a level of 516% is still unacceptably high. To obtain the same reduced value as when "set" is the unit of effort — 21% — the absolute number of hooks that must be observed is 60,329, which is much greater than 100, but still a small number in terms of observed hooks.

LACK OF INDEPENDENCE OF OBSERVER DATA

Sampling theory assumes that the data — e.g., the catches for each purse-seine day fished or each longline hook — are independent and identically distributed (iid). However, if a longline set is made in waters where the availablility of a particular species is high, then each hook in the set will have an equally high probability of catching a fish of that species; if the availability is low, each hook will have an equally low probability. Hence, the data are not independent. The lack of independence decreases as the level of aggregation of effort is increased — from hooks per set, to sets per trip, to trips per vessel.

The lack of independence of the data affects the relationship between the coverage rates and the coefficients of variation of estimates of CPUE through the estimate of the standard deviation of CPUE, i.e., the numerator on the righthand part of equation (5), $\sqrt{\frac{\sum_i^N (u_i - U)^2}{N-1}}$, which is estimated as $\sqrt{\frac{\sum_i^n (u_i - \bar{u})^2}{n-1}}$, where n is the number of units of effort observed. If the data are iid and drawn from a normal distribution with variance σ^2, then $\frac{\sum_i^n (u_i - \bar{u})^2}{\sigma^2}$ follows a χ^2 distribution with $n-1$ degrees of freedom. If the data are not independent, then the degrees of freedom should be corrected, such that the estimate of the standard deviation of CPUE becomes $\sqrt{\frac{\sum_i^n (u_i - \bar{u})^2}{(n-1)\delta}}$, where δ is the correction factor for the degrees of freedom. For example, if the correction factor is 0.5 — such that we have one degree of freedom for every two hooks observed — then the coefficient of variation of the estimate of CPUE will increase by a factor of $\sqrt{\frac{1}{0.5}}$ = 1.414. If the correction factor is 0.1 — one degree of freedom for every ten hooks observed — the coefficient of variation increases by a factor of 3.162. Clearly, the correction factor can have a huge effect of the relationship between coverage rates and the coefficients of variation of the estimate of CPUE.

Two approaches to deal with this problem are to (i) attempt to determine the correction factor for the degrees of freedom or (ii) conduct the analysis using the unit of effort that suffers least from the lack of independance, such as "catch per trip", rather than "catch per hook" or "catch per day fished".

The degrees of freedom can be interpreted as the least number of deviations in a sum of squares that must be known before all remaining deviations can be determined (Li 1964). For example, for a sum of squares of n deviations, it is known that the sum of all deviations, $\sum_{i}^{n}\left(u_i - \bar{u}\right)$, is equal to zero; hence, the n^{th} deviation can be determined from the first $n-1$ deviations, and there are therefore $n-1$ degrees of freedom.

In this present context, this could be interpreted as follows. Given that, for longline, most observed catches per hook are zero, it suffices to know (i) each of the positive values and (ii) the total number of values to determine the mean value and thus the deviations for all of the zero values. The degrees of freedom is then the number of positive values, n_{pos}, and the correction factor δ is $\frac{n_{pos}}{n-1}$. Tables 9 and 10 show the effect of correcting the degrees of freedom with the number of positive observed hooks for offshore longliners targeting albacore, and yellowfin and bigeye, respectively. The ratio of the corrected catch per hook standard deviation to the uncorrected catch per hook standard deviation ranges from 9.5 to 409. If the corrected standard deviations are used in equation (5) instead of the uncorrected standard deviations, the coefficients of variation of estimates of CPUE presented in Figures 6 and 8 will increase by those multiples; hence, defining the degrees of freedom to be the number of positive hooks has a major effect of the coefficients of variation of estimates of CPUE.

Table 9. Effect of correcting the standard deviation of catch per hook (kilograms) for seven species caught by offshore longliners targeting albacore

Species	Catch Per Hook Standard Deviation	Positive Hooks	Corrected Standard Deviation	Ratio
Albacore	1.784032	83,465	16.895903	9.5
Common dolphinfish	0.225176	8,717	6.547547	29.1
Wahoo	0.385927	7,829	11.827478	30.6
Blue shark	1.338442	3,747	59.282774	44.3
Opah	1.154539	1,891	71.935240	62.3
Silky shark	0.561874	775	54.679364	97.3
Black marlin	0.469816	292	74.527473	158.6
Hammerhead sharks	0.186048	44	76.086049	409.0

Table 10. Effect of correcting the standard deviation of catch per hook (kilograms) for seven species caught by offshore longliners targeting yellowfin and bigeye

Species	Catch Per Hook Standard Deviation	Positive Hooks	Corrected Standard Deviation	Ratio
Yellowfin	2.312092	27,093	29.541287	12.8
Bigeye	2.177316	12,861	40.162155	18.4
Blue shark	1.512120	4,364	47.942359	31.7
Blue marlin	1.538456	2,017	71.663519	46.6
Wahoo	0.222905	1,854	10.804654	48.5
Common dolphinfish	0.101486	1,341	5.786417	57.0
Opah	0.701016	571	61.187595	87.3

DISCUSSION

Representiveness of observer data

The relationship between observer coverage rates and the coefficients of variation of estimates of CPUE has been examined for purse-seine trips and purse-seine days fished, and longline sets and longline hooks. These analyses assume that the observer data are representative of the distribution of effort for the gear type and sector for which CPUE estimates are being estimated. In this regard, observer data should be representative in terms of geographic area, season and other factors, e.g., depth of longline sets or school association of purse-seine sets. At present, the purse-seine observer data, and the longline observer data covering the offshore sectors, that are held by the SPC Oceanic Fisheries Programme are generally representative. However, the coverage of longline observer data covering the distant-water fleets (other than Japanese vessels fishing in the waters of Austraia, 1992–1998, and New Zealand, 1992–2008) include only 14 trips targeting yellowfin and bigeye and four trips targeting albacore, out of a total of 3,198 longline observer trips during 1992–2009. It will therefore not be possible to obtain reliable estimates of the total longline catch of non-target species in the region until observer data have been collected from the distant-water sector.

Target coverage rates

The results based on sampling theory presented above suggest that for purse seine, an observer coverage rate on the order of 20% of days fished (Figure 4) should be sufficient to obtain reliable estimates of CPUE for relatively common non-target species. For offshore longline, 3%–5% of hooks set (Figure 6 and 8) should be sufficient. However, for both purse seine and offshore longline, the results also indicate that reliable estimates of CPUE for extremely rare species, including species of special interest (e.g., marine reptiles, marine mammals, sea birds), should only be possible with high coverage.

Comparison of sampling theory to delta-lognormal analyses

Oceanic Fisheries Programme (2007) presents estimates of annual catches and CPUE for various non-target species in the WCPFC Statistical Area. The analyses used the same longline observer data from which the average CPUE and CPUE variation presented in Tables 1–6 were determined, and predicted CPUE with a delta-lognormal (DLN) model including, for purse seine, school association, year, month, latitude, longitude and three oceanographic variables, and for longline, year, month, the number hooks between floats (a proxy for depth), latitude, longitude and three oceanographic variables. Confidence intervals for the estimates of CPUE were determined as the 2.5% and 97.5% quintiles of CPUE estimates resulting from a parametric bootstrap of 1000 replicates taken from the joint distribution of the estimates of the DLN model parameters.

Table 7 compares CPUE coefficients of variation determined from (a) sampling theory (equation 5) and (b) the DLN analyses. For sampling theory, the average levels of observer coverage in recent years — 5.64% of purse-seine days fished, and 0.77% and 0.74% of hooks set by offshore longliners targeting albacore, and bigeye and yellowfin, respectively — were used, together with the average CPUE and CPUE coefficient of variation presented in Tables 2, 4 and 6 (but ignoring the lack of independence of the replicates). The standard error of the CPUE estimates from the DLN analyses was estimated as the average, over years, of one quarter of the confidence interval of the annual estimates of CPUE (which assumes that the confidence interval is roughly equal to plus or minus two standard errors).

It can be seen that the results from the DLN analyses tend to be more uniform, with higher values than those for the lowest values predicted by sampling theory, and lower values than those for the highest values predicted by sampling theory. This may be because the DLN analyses use additional information contained in the independent variables used in the models, rather than just observed CPUE. However, the accuracy of the coefficients of variation determined from the DLN analyses is unknown and should be evaluated through simulations.

Table 11. Comparison of CPUE coefficients of variation from sampling theory and DLN analyses

Gear and Sector	Species	Sampling Theory	DLN Analyses
Purse seine	Silky shark	17.1%	7.7%
	Rainbow runner	21.9%	11.9%
	Whale shark	101.0%	21.7%
Offshore longline targeting albacore	Wahoo	7.5%	8.9%
	Common dolphinfish	3.7%	13.5%
	Blue shark	5.8%	8.0%
	Opah	20.8%	8.9%
	Silky shark	3.6%	24.3%
Offshore longline targeting yellowfin and bigeye	Blue shark	5.4%	7.7%
	Wahoo	13.8%	7.4%
	Common dolphinfish	7.5%	13.8%
	Opah	9.2%	13.5%

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