Catch-per-effort and Stock Status in the U.S. North Pacific Albacore Fishery: Reappraisal of Both

Pierre Kleiber
Christina Perrin
La Jolla Laboratory, Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
P.O. Box 271, La Jolla, California 92038

Abstract.–On reexamining a routine procedure for reporting catch-per-effort (CPE) in the North Pacific albacore fishery, we found evidence that CPE as an index of population size has been subject to a changing degree of bias. The increasing, positive bias in the routinely reported CPE has produced an optimistic, upward trend in this population index during the past decade. A time series of CPE, calculated in a different way, trends downwards. We show that both time series are subject to increasing, positive bias under conditions of an increasing ability of fishermen to locate concentrated patches of albacore. We present evidence that this ability has grown over the past decade, possibly as a result of increasing availability of satellite-based fishing advisories. The divergence of the two time series is explained by a model that shows a different rate of increase in bias in the two cases. The fact that the bias is increasing in the new time series implies that the true population has undergone a more severe decline than is shown by that series.

Manuscript accepted 11 February 1991.
Fishery Bulletin, U.S. 89:379–386 (1991).

The Southwest Fisheries Science Center (SWFSC) has been collecting fishery statistics from the U.S. North Pacific albacore fleet for a number of years. Overall catch-per-effort (CPE) and other summary statistics are included in the deliberations of the International North Pacific Albacore Workshops (Bartoo and Watanabe 1989) and are used to indicate the status of albacore stocks in the region. The history of these assessments has been consistently a favorable outlook of increasing abundance for the stocks, although in recent years the workshop has underscored the lack of detailed information about albacore catch in the growing gillnet fishery in the North Pacific.

The U.S. North Pacific albacore fleet consists primarily of jig vessels which vary in length from 25 to over 100 feet. The effect of vessel length on albacore fishing power was investigated by Laurs et al. (1976). They reported significant variability between 10-foot length-classes of jig vessels. Based on relative fishing power estimates for each year, adjusted effort and CPE values were calculated back to 1961. Since that time the calculation of fishing power and concomitant standardization of effort and CPE has become a routine part of reporting the albacore catch and effort statistics by the SWFSC.

In preparation for the 1989 North Pacific Albacore Workshop, we revisited the theory and rationale behind the effort standardization and calculation of CPE to see if the routine procedures continued to be appropriate. We found that even with standardization for fishing power, there was a high degree of residual variability in CPE within the fishing grounds which was not being addressed. Recalculation of the time series of CPE with a rough correction for such variability showed that the optimistic upward trend over the past decade in the original series was replaced by a downward trend. In an effort to reveal which of the two time series is more representative of the true course of the albacore population, we explored the data in more detail to find what might cause the divergence in the two CPE series. This paper is a report of our appraisal of the routine procedure and our reappraisal of the status of the albacore stocks.

Description of the fishery

The U.S. North Pacific albacore fishery is composed of several surface fishing gears. Trolling vessels (jig boats) are by far the most prevalent, followed by baitboats. They operate primarily in the eastern North Pacific. Other North Pacific fleets that harvest albacore include a Japanese baitboat fleet, operating in the western North Pacific, and wider-ranging Asian longline and gillnet fleets.

Except for the gillnet fleet, catch and effort in the surface fisheries has declined in the past 15 to 20 years. The U.S. commercial catch of albacore dropped from approximately 20,000 metric tons per year in the early 1970s to less than 5000 metric tons in the late 1980s, while effort dropped over the same period from 40,000 boat days to less than 5000 boat days.

The albacore are very patchily distributed, but evolving satellite technology has helped U.S. fishermen to locate areas of high concentration. Albacore tend to migrate along oceanic thermal fronts, and to form transient aggregations in areas where the frontal structures favor local enrichment (Laurs 1983, Laurs and Lynn 1977). These conditions are detectable by satellite (Laurs et al. 1984, Svejkovsky 1988). Over the past decade, increasingly sophisticated fishing advisories have been provided to fishermen. The advisories indicate, from satellite data, the locations of oceanographic conditions conducive to albacore aggregation, and fishermen have been taking increasing advantage of these advisories (Laurs 1989).

The ranges of the population and of the fishing grounds are variable both within the fishing season and from year to year. Albacore in the size range vulnerable to the U.S. fishery are entrained in an annual east-west migration pattern. The U.S. fishery peaks during the summer and autumn months when the albacore are closest to the North American coast. Albacore appear to be separated into northern and southern subgroups divided approximately by the 40°N latitude line (Laurs and Lynn 1977). The timing and extent of albacore migration are variable and without synchrony between the two subgroups. The location of oceanic fronts is also variable. As a result, the boundaries of the fishing grounds are extremely ill-defined and fluid, as is the extent to which the fishing ground overlaps the range of the albacore population. The traditional U.S. fishery is primarily nearshore. However, in the past 10 years, jig boats have been venturing farther offshore, some as far west as the dateline, earlier in the season in an attempt to meet the migrating albacore on their way toward the North American coast.

Theory and methods

The routine procedure for estimating fishing power in the U.S. albacore fleet makes use of a computer program, FPOW, coded by the California Department of Fish and Game and described by Fox (1971) and Berude and Abramson (1972). The basic theory behind this program is described by Robson (1966). The heart of the method is an analysis of variance which seeks to account for variation in the logarithm of CPE due to vessel length-classes, as well as to other factors such as time-area strata. Unlike usual analysis of variance, FPOW concentrates on reporting estimates of the coefficients in the statistical model. These coefficients are the logs of the fishing power of vessel classes relative to that of a reference class (45-foot vessels in this case). FPOW does not list a table of residual variances and F statistics, which would indicate the degree of statistical significance of the various factors. Accordingly, for the most recent year for which we had data (1988), we used a different analysis of variance program (BMDP) to better reveal the significance of variation due to vessel length in relation to other sources of variation.

As we looked into the routine procedure for aggregating catch and effort over all the time-area strata in a year, we found that effort (standardized for vessel length) and catch in the individual strata have been summed over strata, and a pooled CPE given by

$$\mathrm{CPE}_{\mathrm{pooled}} = \frac{\sum c_i}{\sum e_i} \tag{1}$$

has been calculated, where c_i and e_i are the catch and effort in the i-th stratum. In the case where population density varies between strata, it is well known that such a pooled CPE is not a good population index because even though CPE might be proportional to population density in individual strata, that proportionality is destroyed with a pooled CPE. However, that proportionality can be maintained with a stratified CPE given by

$$\mathrm{CPE}_{\mathrm{strat}} = \frac{1}{N} \sum \left[\frac{c_i}{e_i} \right] \tag{2}$$

where N is the number of strata (Beverton and Holt 1957:148–151). This is simply the average of CPE-s in individual strata. An effort aggregation scheme that in effect does the same thing has been used for the Japanese longline fishery for albacore (Honma 1974).

Strictly speaking, Equation 2 presumes that there is at least some effort in all strata. When that is not true, estimates should be provided of what CPE would have been in each of the missing strata had the fishery visited them. In the case of the U.S. North Pacific albacore fishery, the fluid nature of the fishing grounds described above makes it difficult to say whether a given stratum should be considered missing or not present in the fishing ground for a particular year. For the purpose of our new CPE series, we ignored the problem by ignoring unvisited strata. However, if the visited strata were not a random sample of available strata, the average CPE would be biased. To the extent that fishermen are able to locate strata with higher than normal population density, we expect them to favor those strata. Therefore, we expect that our new CPE values are only partially corrected for the effects of heterogeneous population density.

Either of the CPE series would still be useful, even though biased, as long as the bias does not change over time. But as noted above, the character of the fishery has been changing. The declining effort over the past approximately 20 years could lead to differential dropout of the less able fishermen, and the increasing availability and use of advisories in the past approximately 10 years could be increasing the ability of the remaining fishermen. The salient ability in this case is that of locating concentrations of albacore. If that ability has been changing, the bias in both old and new CPE time series must also be changing. We will show that the rate of change in bias is different in the two time series.

It would be useful to document the fact that the fishery is increasingly favoring high-abundance strata. Gulland (1956) suggested that the ratio of pooled to stratified CPE could be used as an index of effort concentration. But in this case we do not have a proper stratified CPE because of the problem of missing strata. We have devised a different favoritism index which is the proportion of the effort in any year that is expended in strata with a CPE above some threshold value, CPE^*. The favoritism index in year y is given by

$$\text{favoritism index}_y = \frac{\sum_{i \in T_y} e_i}{\sum_{i=1}^{N_y} e_i};$$

$$T_y = \{ i \mid (c_i/e_i) \geq \mathrm{CPE}_y^* \} \qquad (3)$$

where T_y is the set of stratum indices for which CPE is greater than CPE_y^*, and CPE_y^* is determined by ranking the strata in year y according to CPE and choosing the minimum CPE of the top 20th percentile of the strata.

Data

Our data source is voluntarily contributed logbook information from the U.S albacore fishery. It is maintained on a database by the SWFSC and covers the years 1961 to 1989. The portion of landings sampled each year varies from 15% to 61%.

For analysis of variance, we used the 1988 data, the most recent year available at the time the analyses were conducted. As with the routine standardization procedure, we selected only jig boat records and organized the data by four large strata—early north, late north, early south, and late south—where the division between the early season and the late season is 1 September, and the division between north and south is 38°N latitude. Again following the routine procedure, within the large strata we treated the data by smaller time-area strata consisting of 3° latitude-longitude squares and half-month time periods, and classified vessels by 10-foot length classes. In contrast to the routine procedure, we maintained records of individual vessels within strata and length classes to allow analysis of variance with replicates. For calculating the CPE time series, we utilized 1° latitude-longitude strata, which is the finest resolution available.

Results and discussion

We conducted several analyses of variance with various subsets of the data, using CPE or ln(CPE) as the dependent variable.[*] Vessel length appears to be a significant factor in relatively few of these analyses (Table 1) whereas time-area stratum is almost always highly significant (low probability under H_0). Because the two-way analyses were unbalanced (unequal number of replicates), effects of the two factors could be confounded to some extent, and rigorous interpretation of the results is difficult. The salient features of the analyses are (1) that vessel size is of questionable significance as a factor influencing CPE, and (2) that time-area stratum tends to have a much higher statistical significance than does vessel size. In other words, it appears that vessel size does not matter nearly as much as where the vessel is and when.

Regardless of its statistical significance, the practical significance of vessel size in the context of reporting effort and CPE can be tested by seeing whether substantially different results are obtained with and without vessel size standardization. We recalculated the 1961 to 1989 time series without such standardization and found very little difference in CPE trends (Fig. 1). There appears to be little point in standardizing for fishing power even though vessel size may be statistically significant in some cases.

The emphasis on accounting for the effect of vessel size has obscured a more prominent feature of variability in CPE, which is the effect of location and time.

---

[*] In the routine standardization, ln(CPE) is the dependent variable, and instances of zero catch with positive effort are ignored.

Table 1

Probability under H_0 (no effect) for vessel class (size) and time-area (strat) from one-way and two-way analyses of variance on various subsets of 1988 North Pacific albacore catch-and-effort data, and either CPE or ln(CPE + 1) as dependent variable.

	1- or 2-way	Source	Early season log(CPE+1)	Early season CPE	Late season log(CPE+1)	Late season CPE
North	1	size	0.15	0.001	0.46	0.42
	1	strat	<0.001	<0.001	<0.001	0.03
	2	size	0.03	<0.001	0.29	0.29
		strat	<0.001	<0.001	<0.001	0.03
South	1	size	0.009	0.035	0.66	0.48
	1	strat	<0.001	<0.001	0.22	0.84
	2	size	–	–	0.57	0.20
		strat	–	–	0.23	0.63

	1- or 2-way	Source	Whole season log(CPE+1)	Whole season CPE
North and South	1	size	<0.001	<0.001
	1	strat	<0.001	<0.001
	2	size	0.30	<0.001
		strat	<0.001	<0.001

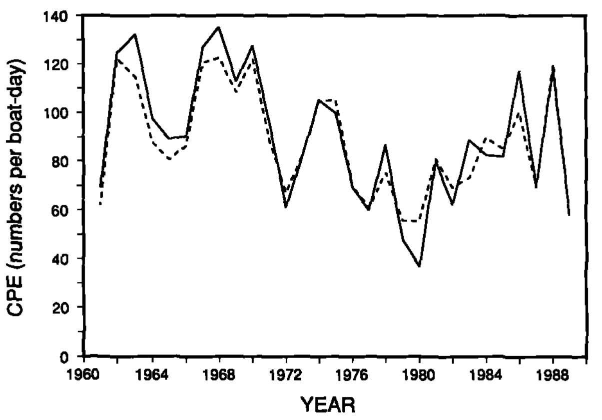

Figure 1

Comparison of original catch-per-effort time series (solid line) with unstandardized catch-per-effort (dashed line) for North Pacific albacore. Both time series are pooled catch-per-effort based on Equation 1. Effort values in the original time series are standardized for size of fishing vessels. Effort values in the other time series are not standardized.

This variability is not taken into account in the existing routine procedure. Our new time series, based on Equation 2 with unvisited strata ignored, gives a noticeably different picture (Fig. 2). The pronounced rising trend since 1978 in the old time series is replaced by a continuing downward trend.

The new CPE time series in Figure 2 was calculated without regard to the time sequence within a fishing season, that is, all spatio-temporal strata in a particular year were entered into the average for that year. If the fishery has not been fully covering the season in which albacore are available in the eastern Pacific, and if there has been a trend in the degree of coverage, then the yearly averages in Figure 2 could reflect that trend rather than a trend in the albacore population. We calculated a detailed time series with a separate $\mathrm{CPE}_{\mathrm{strat}}$ for each 10-day period (Fig. 3) to look at the temporal pattern of CPE within seasons. In some years such as 1970, 1976, and 1989, it appears that the fishery may have missed a portion of the season of availability of albacore in the eastern Pacific. The CPE was already high at the beginning of the fishery, or the fishery quit before the CPE had tapered off. In most years, however, the fishery appears to have been active from the arrival of the albacore at the fishing ground to their departure. There does not seem to be a trend in the degree of coverage. In any case, it is not clear that variation in the degree of coverage would affect the old and new time series differently.

Another factor that might cause a divergence between the old and new time series of CPE would be an increasing ability of fishermen to locate areas of high albacore abundance. We will demonstrate that this is so with a simple model. Suppose there are two kinds of strata in the fishing ground, ones with low abundance and ones with high abundance, such that the population density within each type is d_l and d_h respectively, and $d_l < d_h$. We assume that CPE is proportional to fish density within the strata. Therefore we can measure d_l and d_h in catch-per-effort equivalents. Suppose further that there are n_l and n_h of each type of stratum in the fishing ground. If the fishery showed no favoritism for either type, then the probability of one unit of effort visiting any particular stratum would be $1/(n_l + n_h)$. We can model favoritism by defining p_l and p_h to be the probabilities that a unit of effort would visit a particular low-abundance or high-abundance stratum. We then let

$$p_l = \frac{1}{n_l + \alpha n_h}; \quad p_h = \frac{\alpha}{n_l + \alpha n_h} \tag{4}$$

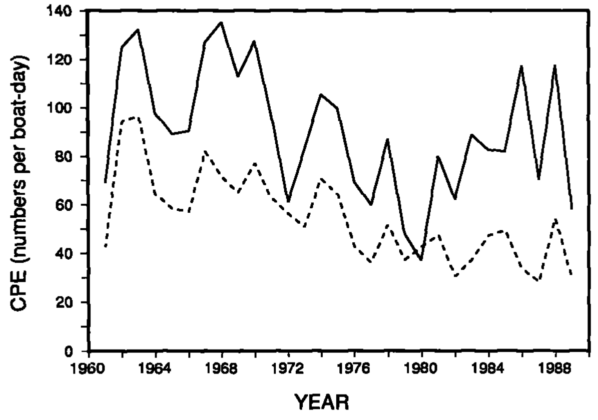

Figure 2

Comparison of original catch-per-effort time series (solid line) with a new catch-per-effort time series (dashed line) for North Pacific albacore. The original time series (CPE_{old}) is the same as the solid line in Figure 1. The new time series (CPE_{new}) is calculated using Equation 2 and ignoring strata with no effort.

where α is a favoritism coefficient. When α equals 1, the probability of a stratum of either type being visited is the same, and there is no favoritism. But as α increases, the chance for any high-abundance stratum is increased at the expense of the chance for any low-abundance stratum. Note that the sum of probabilities over all strata, $n_l p_l + n_h p_h$, is equal to 1, so that it is certain that a given unit of effort will land somewhere in the fishing grounds.

The probability that any particular stratum will receive a particular visit is $n_l p_l$ for low-density strata and $n_h p_h$ for high-density strata. The expected total number of visits is $e_{tot} n_l p_l$ to any of the low-density strata and $e_{tot} n_h p_h$ to any of the high-density strata, where e_{tot} is the total effort expended by the fishery. Therefore,

$$E[C_l] = e_{tot} n_l p_l d_l; \quad E[C_h] = e_{tot} n_h p_h d_h \qquad (5)$$

where C_l and C_h are the catches from all the low-density and high-density strata, respectively, and d_l and d_h are measured in CPE equivalents.

The old CPE is the total catch over total effort. Its expected value is thus,

$$E[CPE_{old}] = \frac{E[C_l] + E[C_h]}{e_{tot}} = n_l p_l d_l + n_h p_h d_h. \qquad (6)$$

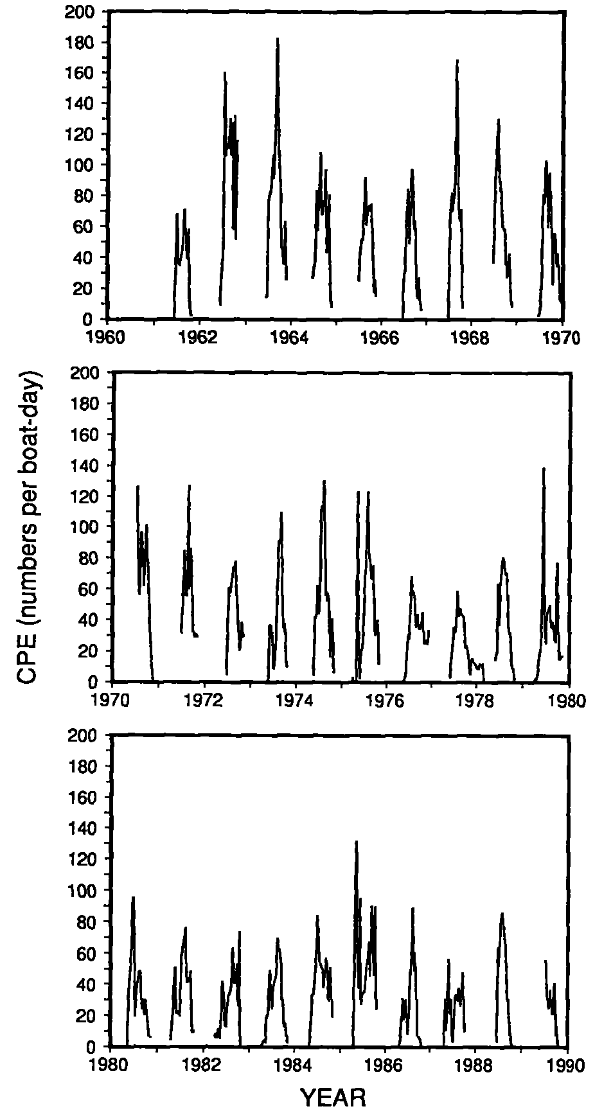

Figure 3

Detailed time series of stratified catch-per-effort for North Pacific albacore calculated for every ten-day period using Equation 2 and ignoring strata with no effort.

To calculate the new CPE, we need the number of strata in each area with at least one visit, v_l and v_h. To get these, we will first derive the number of low- and high-density strata that are missed altogether. The probability that a particular stratum is missed by a particular effort unit is $1 - p_l$ for low-density strata and $1 - p_h$ for high-density strata. The probability that a particular stratum is unvisited by any effort unit, that is, missing in the data, is thus,

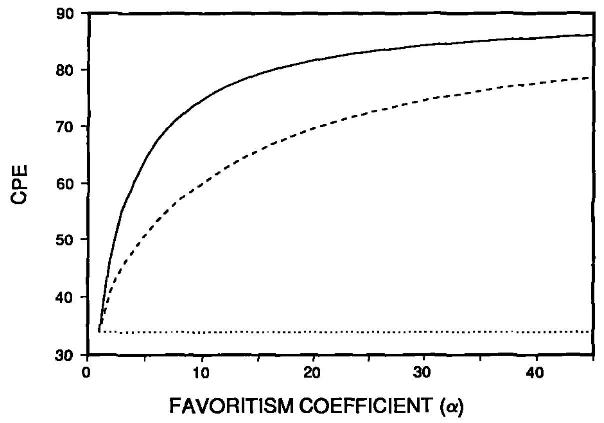

Figure 4
Catch-per-effort for North Pacific albacore predicted by model as function of favoritism coefficient, α, which reflects the ability of fishermen to locate fish concentrations. The expected values of CPE_{new} (solid line) and CPE_{old} (dashed line) are compared with the true mean population density in CPE equivalents (dotted line). The maximum error in the approximation for $E[CPE_{new}]$ is less than 0.7 CPE units in all cases.

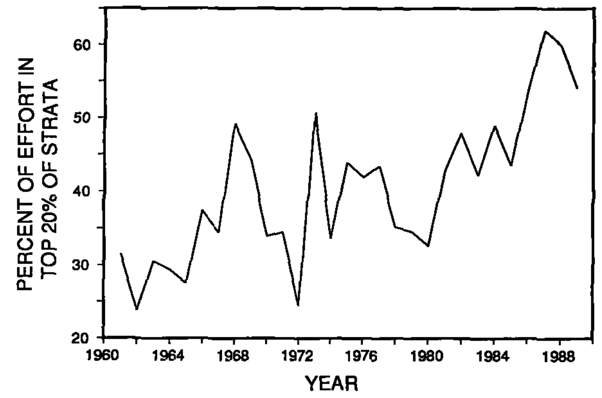

Figure 5
Favoritism index of vessels fishing for North Pacific albacore, calculated using Equation 3. The index measures the degree to which fishermen concentrate on strata with high fish populations. It is the proportion of effort in each year exerted in the top 20th percentile of strata where strata are ranked by catch-per-effort.

$$P[\text{stratum i missing}] = \begin{cases} (1-p_l)^{e_{tot}} & \text{if i in low-density area} \\ (1-p_h)^{e_{tot}} & \text{if i in high-density area.} \end{cases} \tag{7}$$

In each area the expected number of strata with at least one visit is the total minus the expected number of missing strata. Thus,

$$E[v_l] = n_l - n_l(1-p_l)^{e_{tot}}; \quad E[v_l] = n_h - n_h(1-p_h)^{e_{tot}}. \tag{8}$$

The new CPE is the average over the visited strata of the CPE values observed therein, that is,

$$CPE_{new} = \frac{v_l d_l + v_h d_h}{v_l + v_h}. \tag{9}$$

The functional form of Equation 9 does not allow substitution of expected values of v_l and v_h to get the expected value of CPE_{strat} exactly. However, it has been shown for a similar situation that it is a close approximation as long as the expected number of visited strata is not too small (Deriso and Parma 1988). The expected value of the new CPE is approximated by

$$E[CPE_{new}] \approx \frac{E[v_l]\, d_l + E[v_h]\, d_h}{E[v_l] + E[v_h]} \tag{10}$$

with an error less than $(d_l + d_h)/(E[v_l] + E[v_l])$ based on Deriso and Parma's formulation.

With some straightforward algebra it can be shown that when $\alpha = 1$ (no favoritism), $E[CPE_{old}]$ and $E[CPE_{new}]$ are both equal to the true mean population density (in CPE equivalents), that is,

$$\alpha = 1 \implies E[CPE_{old}] = E[CPE_{new}] = \frac{n_l d_l + n_h d_h}{n_l + n_h}. \tag{11}$$

It can furthermore be shown that as α increases above 1, $E[CPE_{old}]$ and $E[CPE_{new}]$ rise monotonically and approach d_h as α gets large (Fig. 4). Thus, old and new CPE are both unbiased when there is no favoritism; the bias increases at different rates for the two as favoritism increases; and they both approach the same bias as favoritism becomes large.

Relating the model results back to the U.S. North Pacific albacore fishery, we presume that an increasing ability to locate high-abundance strata is equivalent to a rising value of favoritism (α) in the model. The divergence of the old and new time series (Fig. 2) indicates that the effective α has been increasing toward some intermediate level. Changes in the fishery in the past decade—increasing availability and use of fishing advisories and severe decline in effort with the possibility of differential loss of less-able fishermen—are consistent with such a change in α.

In searching for corroborative evidence that the fishery has been increasingly concentrating on high-abundance strata, we found that the favoritism index given by Equation 3 has been tending upwards, particularly over the last decade (Fig. 5). This coincides well with the divergence in the old and new time series of CPE starting around 1979 (Fig. 2). Given this evidence of increasing ability to locate aggregations, the recovery in the old CPE time series in the past decade reflects a change in fishing operations and not a recovery of the albacore stocks. In fact, if the albacore population had just been holding its own over that time, the new time series should also have been rising because it is also subject to increasing positive bias. The fact that it has been declining indicates that the population must have been declining even more rapidly.

Though we have not invented a new population index, free of variable bias, the different effect of bias on our new CPE time series and the original CPE time series has helped reveal a change in fishing operations. This change has markedly affected our interpretation of CPE in the United States North Pacific albacore fishery. To reveal population trends with an unbiased time series requires that we deal with unvisited strata. The difficulties of doing so are great with the type of spatio-temporal variability that we have in the North Pacific albacore fisheries. Attempts are being made (R. Mendelssohn, NMFS Southwest Fish. Sci. Cent., Monterey, CA, pers. commun.) with the inclusion of fishery-independent data (environmental data in this case) to infer CPE in unvisited strata.

Conclusion

We have reexamined the details and justification for a routine procedure for processing catch-and-effort data from the U.S. Pacific albacore fleet. We have found that the use of estimates of fishing power to account for variation in catch rates due to vessel size is of negligible value. Standardizing effort for vessel size has had little effect on the observed time series of effort and CPE in this fishery.

On the other hand, the patchy distribution of albacore is of great importance. In the routine procedure for reporting overall fleet effort, the concentration of effort on areas of high abundance has been dealt with inappropriately, so that CPE trends are unrelated to trends in the population available to the fishery. The new CPE, which is an incomplete correction for concentration of effort, reverses what has been seen as a rising trend in abundance over the past decade.

We have shown that the divergence of the old and new time series is consistent with a fishery for a patchily distributed resource and a growing ability to locate high-density patches. Such a scenario is confirmed by detailed examination of changes in the distribution of catch and effort in the fishery. This change is probably due to increasing use of advisories aimed at locating dense albacore patches, but other possible contributing factors include the differential dropout of less-able fishermen from the fishery or a decreasing representation of less-able fishermen in the sampled landings. Whatever the cause, we have shown that in such a scenario, the original time series would have an increasing positive bias as an index of population, and the new series would also have an increasing positive, but reduced, bias. The nature of the fishery is such that we cannot calculate a reliably unbiased index of population based solely on the fishery data. However, the implication of our results is that the actual trend in the population should have been a more severe decline than is indicated by the new time series.

Citations

Bartoo, N., and Y. Watanabe
1989 Report of the eleventh North Pacific albacore workshop. Admin. Rep., LJ-89-24, Southwest Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, La Jolla, CA, 17 p.

Berude, C.L., and N.J. Abramson
1972 Relative fishing power, CDC 6600, FORTRAN IV. Trans. Am. Fish. Soc. 101:133.

Beverton, R.J.H., and S.J. Holt
1957 On the dynamics of exploited fish populations. U.K. Min. Agric. Fish., Fish. Invest. (Ser. 2) 19, 533 p.

Deriso, R.B., and A.M. Parma
1988 Dynamics of age and size for a stochastic population model. Can. J. Fish. Aquat. Sci. 45(6):1054.

Fox, W.W.
1971 User's guide to FPOW: A computer program for estimating relative fishing power and relative population density by the method of analysis of variance. Univ. Wash. Quant. Sci. Pap. 27, 6 p.

Gulland, J.A.
1956 A study of fish population by the analysis of commercial catches. Rapp. P.-V. Reun. Cons. Int. Explor. 130:21–27.

Honma, M.
1974 Estimation of overall effective fishing intensity of tuna longline fishery. Bull. Far Seas Fish. Res. Lab. (Shimizu) 10:63–66.

Laurs, R.M.
1983 The North Pacific albacore — An important visitor to California Current waters. Calif. Coop. Oceanic Fish. Invest. Rep. 24:99–106.
1989 Applications de la télédétection satellitaire du germon du Pacifique Nord, *Thunnus alalunga* (Bonnaterre). *In* Le Gall, J.-Y. (ed.), Télédétection satellitaire et pêcheries thonières océaniques. FAO Document technique sur les pêches 302. FAO, Rome, 148 p.

Laurs, R.M., and R.J. Lynn
1977 Seasonal migration of North Pacific albacore, *Thunnus alalunga*, into North American coastal waters: Distribution, relative abundance, and association with transition zone waters. Fish. Bull., U.S. 75:795.

Laurs, R.M., H.B. Clemens, and L.H. Hreha
1976 Nominal catch-per-effort of albacore, *Thunnus alalunga* (Bonnaterre), caught by U.S. jig vessels during 1961–70. Mar. Fish. Rev. 38(5):1–32.

Laurs, R.M., P.C. Fiedler, and D.R. Montgomery
1984 Albacore tuna catch distributions relative to environmental features observed from satellites. Deep-Sea Res. 31(9): 1085.

Robson, D.S.
1966 Estimation of the relative fishing power of individual ships. ICNAF Res. Bull. 3:5–14.

Svejkovsky, J.
1988 Remotely sensed ocean features and their relation to fish distributions. *In* Sproule, D.F., and G.S. Klepple (eds.), Marine organisms as indicators, p. 177–197. Springer-Verlag, NY.