Effect of migration on achievement of proportional harvest under a system of survey apportionment of total catch

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Abstract

Apportioning catches among areas in proportion to a snapshot of biomass distribution will not necessarily result in equal fishing mortality rates in all areas if there is net migration occurring. But the differences are at most small at the rates of migration likely to occur in halibut, and if the snapshot of biomass distribution is taken at midseason, when the IPHC setline survey is done, there is no difference. The survey apportionment of halibut biomass and yield should result in equal rates of instantaneous fishing mortality in all areas even in the presence of migration.

Background

In the 2006 stock assessment, owing to concerns about the effect of migration on closed-area assessments, the staff estimated coastwide biomass with a coastwide model fit and then apportioned the coastwide estimate among regulatory areas in proportion to a survey index of biomass in each area (survey CPUE multiplied by bottom area out to 300 fm). This apportionment relies strongly on the assumption of equal survey catchability among areas, which is reasonable but questionable. And even if survey catchability is equal, there is some question as to whether the survey apportionment of yield will really achieve the Commission's goal of proportional harvest among areas when fish are migrating before and after the survey. This paper addresses that question.

The first step is to define terms precisely. In fishery science the terms "exploitation rate" and "harvest rate" have the same technical meaning, which is the catch as a fraction of the initial number present or $u = C / N_0$ where u is the rate of exploitation, N_0 is the number of fish present in an area at the beginning of the season, and C is the catch in number during the season (Ricker 1975). When fishing and natural mortality are treated as continuous processes, and there is no net migration, the rate of exploitation is determined by the Baranov equation, which is $u = F \cdot \left(1 - e^{-(F+M)}\right) \Big/ \left(F + M\right)$ with F denoting the instantaneous rate of fishing mortality and M the instantaneous rate of natural mortality. The instantaneous rate of total mortality is $Z = F + M$ and the number of fish surviving to time t during the season is $N_t = N_0 \cdot e^{-Z \cdot t}$. With Z substituted for $\left(F + M\right)$, the Baranov catch equation is $C = u \cdot N_0 = N_0 \cdot F \cdot \left(1 - e^{-Z}\right) \Big/ Z$.

Migration complicates the calculations but not greatly. The effect of emigration on the number of fish present in an area is the same as the effect of an addition to natural mortality, and the effect of immigration is the same as the effect of a reduction in natural mortality. Let X denote the instantaneous rate of net emigration from an area. Then $Z = F + M + X$. The Baranov equation still holds, but a higher rate of fishing mortality F is needed to achieve a given exploitation rate u in competition with emigration as well as natural mortality. Likewise if there is net immigration into an area at a rate X, we have $Z = F + M - X$ and a lower F can achieve the same exploitation rate.

The Commission's goal of proportional harvest really means achieving the same rate of instantaneous fishing mortality in all areas. It would not be proper to achieve the same rate of exploitation in all areas if that required applying a high rate of instantaneous fishing mortality in emigrant areas and a low rate in immigrant areas. Instead the aim is for fish to encounter the same rate of instantaneous fishing mortality wherever they go.

From this point of view the yield apportionment proposed by the staff is suspect, because it applies the same exploitation rate to both emigrant and immigrant areas without any consideration of the implied instantaneous rates of fishing mortality. The remainder of this paper reports calculations of the implied instantaneous rates.

Apportionment based on stock distribution at the beginning of the season

Consider as a simple hypothetical example a stock that occupies two regulatory areas of equal size, Area 1 and Area 2. Suppose that an equal number $N1 = N2 = 1000$ recruits appears in each area at the beginning of the year, and that we have good estimates of the equal numbers in the two areas at that time. Further suppose that our target rate of exploitation is $u^* = 0.20$, and we set a target catch of 200 fish from each area accordingly. If there is no net migration between the areas, and if natural mortality $M = 0.15$, the instantaneous rate of fishing mortality in both areas will be $F^* = 0.242$, the intended rate.

But suppose there is a net emigration from Area 1 to Area 2 at a rate $X = 0.05$, and as a simplifying approximation treat this as immigration into Area 2 at the same rate $X = 0.05$. The rates will be the same at the start of the year, but by the end of the year emigration at a 0.05 rate from Area 1 will be slightly less than a 0.05 rate of immigration into Area 2 (about 0.045). The calculations will therefore slightly overstate the effects of migration, but the approximation is quite close and it greatly simplifies the analysis.

The number of fish in Area 1 as the year progresses will be governed by $Z1 = F1 + M + X$. The value of $F1$ required to achieve the target catch there is $F1 = 0.248$. In Area 2 the number of fish is governed by $Z2 = F2 + M - X$, and the required fishing mortality is $F2 = 0.235$. If X were 0.10 rather than 0.05, the resulting rates would be $F1 = 0.255$ and $F2 = 0.229$. So there is some disparity in realized instantaneous fishing mortality rates in this case, but it is small.

Apportionment based on stock distribution during the season

The apportionment used by the staff is based on estimated relative abundance at the time of the survey, which is halfway through the year. At that time the number of fish present is $N_0 \cdot e^{-Z/2}$. This midyear number is naturally very close to the average number present during the course of the year, which is $N_0 \cdot \left(1 - e^{-Z}\right) / Z$, so the effect of an apportionment based on midyear abundance can be studied using either expression.

In our hypothetical case, midyear abundance in Area 1 will be lower than in Area 2 because $Z1 > Z2$, so less than half the yield will be allocated to Area 1. This will move both $F1$ and $F2$ toward the target rate F^*. The actual rates that will result from this apportionment must satisfy two conditions: the catch from each area must be proportional to the value of $N_0 \cdot \left(1 - e^{-Z}\right) / Z$ in each area, and the sum of the catches must equal the target catch from both areas. Written out, the second condition is:

$$F1 \cdot N1 \cdot \left(1-e^{-Z1}\right) \Big/ Z1 \ + \ F2 \cdot N2 \cdot \left(1-e^{-Z2}\right) \Big/ Z2 \ = \ F* \cdot \left(N1+N2\right) \cdot \left(1-e^{-Z*}\right) \Big/ Z*$$

It is clear from this equation that $F1$ and $F2$ must be equal, because otherwise the catches would not be proportional to the values of $N_0 \cdot \left(1-e^{-Z}\right) \Big/ Z$. And in this case they must both be nearly equal to $F*$ in order to achieve the target catch because $\left(1-e^{-Z}\right) \Big/ Z$ is nearly linear in Z and $Z*$ is midway between $Z1$ and $Z2$. Simulation results bear this out; the equilibrium values of $F1$ and $F2$ are equal, and their value is equal to $F*$ to three decimal places. So a midyear apportionment results in fishing at the same instantaneous rate in both areas even when there is some net migration.

The results from this simple example extend to the case of several areas with possibly different sizes and possibly unbalanced migration rates because an equation like the one above must be satisfied by the operation of the midyear apportionment procedure. Using subscript *a* to denote area, the equation is:

$$\sum_a F_a \cdot N_a \cdot \left(1-e^{-Z_a}\right) \Big/ Z_a = F* \cdot \left(\sum_a N_a\right) \cdot \left(1-e^{-Z*}\right) \Big/ Z*$$

All of the $\{F_a\}$ must be equal; denote this value $\tilde{F}$. The equation can then be written:

$$\tilde{F} \cdot \sum_a N_a \cdot \left(1-e^{-Z_a}\right) \Big/ Z_a = F* \cdot \sum_a N_a \cdot \left(1-e^{-Z*}\right) \Big/ Z*$$

The summation on the left is just the coastwide sum of the average numbers in all areas. The summation on the right is the sum of the average numbers that would occur if all of the $\{Z_a\}$ were equal to $Z*$. At any moderate levels of migration these two values will be nearly equal, so $\tilde{F}$ will be nearly equal to $F*$.

References

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191: 382 p.