A CHALLENGE OF ACCEPTED CONCEPTS INVOLVING CATCH PER UNIT OF EFFORT DATA

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Abstract. A commonly held assumption, that a unit of fishing effort catches a constant proportion of the fishable population at all population levels, is examined. Inspection of California's Pacific sardine, Pacific mackerel, and tuna fisheries leads to the conclusion that a nominal unit of fishing effort takes an increasingly larger proportion of the fish population as the population declines, and that the rate of change of the catchability coefficient relative to changes in population size is dependent on the nature of the specific fishery in question. This concept, a catchability coefficient which increases continuously in a declining population, contradicts the concept of "equilibrium catch" at all effort levels, predicted by Schaefer's model, and casts doubt upon the validity of certain controlled-entry fishery models.

Professor Baranoff, a Russian, is generally credited as being the father of the theory of fishing and the catalyst for the subsequent profusion of fish population dynamics literature. Baranoff's two papers, "On the Question of the Biological Basis of Fisheries," and "On the Question of the Dynamics of the Fishing Industry," were published in Moscow in 1916 and 1925, respectively. William Ricker, who was then at Indian University, translated both of Baranoff's papers into English in 1945.

Baranoff indicates the objectives of his first paper by quoting Henle as follows:

> "An hypothesis, refuted by new facts, dies an honorable death. If it has done nothing more than evoke the facts which refuted it, it has earned the right to become a monument esteemed forever."

He also pointed out in his forward that his paper was an attempt to elucidate theoretically some questions on fish bionomics and that it was presented as material for a working hypothesis. Although he began his paper somewhat modestly with the caution that the assumptions and correlations advanced need to be tested, he finished his paper more positively.

He assumes in his model that fish are distributed evenly over the bottom of the fishing area. He also assumes that his unit of gear, a trawl, will take a constant percentage of fish within the swath of the trawl. His "elemental fishing intensity" is the percentage of fish caught within the swath of the trawl times the ratio of that swath to the total area. From this it follows that a unit of Baranoff's "real elemental fishing intensity" represents a constant proportion of the fish population. This assumption, and others he made, seemed to hold up under the test of real data from the North Sea plaice fishery. As a result of the initial success with plaice, the assumption,that a unit of effort takes a constant proportion of the fish population has persisted in the proliferation of fisheries models from that time on, with little or no attempt to confirm or test the assumption, or even examine it closely. Some authors state the assumption as Schaefer does when he assumes that a unit of gear catches a constant proportion of the fishable population (Schaefer, Milner B. Some aspects of the dynamics of populations important to the management of the commercial fisheries. Inter. Amer. Trop. Tuna Commiss. Bul.:Vol. 1, No. 2. 1954). Even those authors who do not state it rely on it since it is implicit in almost all fisheries models.

It is my contention that a given unit of fishing effort takes an increasingly larger proportion of the fish population as the population declines. Another way of stating this is the catchability coefficient is a variable which is negatively related to fish population size. This is contrary to present use, which regards the catchability coefficient as a constant.

The rate at which efficiency of effort increases as the stock declines depends upon the nature of the specific fishery. This effect would be more pronounced in a fishery which tends to depend on hunting for fish, which are contagiously distributed, and on communication between fishermen, than in a fishery in which effort units are fished somewhat independently of each other on stocks which tend to be uniformly distributed over the fishing area.

The reasons for this are: any usable units of fishing effort such as a day's fishing, an hour's fishing, the set of a purse seine, length of a standard drag, etc. ultimately relate in some way to effort expended by man--consequently, they cannot be considered as independent effort units; many species of fish tend to school up in certain areas more often than in others; fishermen tend to fish in areas where they had previously caught fish; and fishermen communicate with each other.

Let me give an example: when the sardine fishery began off the coast of California, the sardine population obviously was very large. Fish were caught quickly, easily, and close to port. In fact, catches tended to saturate gear, making it difficult to determine different population levels on the basis of catch-per-effort. The sardine population had to decline somewhat before any change in the catch-per-effort could be noticed. As the sardine population became smaller, fishermen found that the fish were not distributed in a random manner. Sardine schools tended to cluster--usually in certain areas more often than in others. Sardine fishermen, therefore, searched in a non-random manner. They tended to search where their own experience revealed they would be more apt to find sardines, and because sardine fishermen were capable of thinking and communicating with each other, they did not search independently. Each fishing boat operator was able to find out where fish were caught the previous night and increase his opportunity for success on a given night.

As the population declined further, the ship's radio became more important as did echo-sounding equipment, both of which are less important at higher population levels when fish may be encountered shortly after leaving the harbor. Using radios, the entire fleet becomes alerted to where fish are being caught, allowing the fleet to converge on clusters of schools to make better catches than they would have if they fished in a random manner on fish which were randomly distributed. Mobility of effort in relation to the fishing area was great in the sardine fishery since boats delivered fish which were caught from any part of the fishing area to the cannery each morning.

As fish become scarcer, there is a continually increasing dependence on communication, radios, and echo-sounders, and eventually airplanes are used to locate fish and even help fishermen set their nets around schools. All of these factors--communication, clustering of fish schools, intelligent and non-random behavior of the fishermen, high mobility of effort in relation to the fishing area, and increased reliance on gear which aid communication and efficiency--tend to increase continuously the proportion of the fish population taken by a unit of gear as the population becomes smaller. As the fish population increases, use of airplanes is discontinued and dependence on communication also decreases.

The fisherman is interested in maximizing his profit. He is not interested in randomly sampling the population to find out where fish are not abundant as well as where they are abundant. He fishes in areas where his probability of success is the greatest. If you wanted to design a survey to determine the adundance of fish off the coast, it would be difficult to design a more biased sampling scheme than one using catch-per-effort from the commercial fishery.

This bias, which is a result of the factors mentioned, causes the catchability coefficient to increase continuously as the fish population declines. Therefore, if a fish population is overfished at a given effort level, the catch should not come to an equilibrium at some lower level as Schaefer's model predicts, but it should continue to decline until the fishery becomes commercially extinct, unless fishing effort is reduced. Furthermore, at each successive lower population level, effort would have to be reduced to a still lower level in order to start the population trend upward. The sardine fishery off the coast of California certainly appears to have behaved this way.

Richard H. Parrish has shown that the rate of exploitation of poor year-classes of Pacific mackerel off California is higher than that of strong year-classes (Parrish, Richard H. Exploitation and recruitment of Pacific mackerel, (*Scomber japanicus*) in the northeastern Pacific, CalCOFI Reports, in press). This is precisely what should be expected in a purse seine fishery with the characteristics of the Pacific mackerel fishery.

New innovations which tend to increase efficiency usually are adopted over a period of time. These changes in a fishery are usually analyzed and the catch data are corrected. Once adopted, most of these innovations are considered to be fully in effect from then on. All that is needed is a simple adjustment to the fishing effort. However, to the contrary, one should expect that improvements such as the radio and airplane would have the effect of increasing the rate that the efficiency of a unit of gear changes in relation to changes in fish abundance. In other words, efficiency of a unit of effort is negatively correlated with population size regardless of improvements, but the rate at which efficiency increases as the population declines would be affected by such improvements.

Certain controlled-entry fishery models are dependent on managing fisheries at the maximum equilibrium economic yield. They assume that the biological concept of "equilibrium catch" is valid--that the catch will come to some equilibrium at any expenditure of effort. Certain of these economic models also assume a stability of effort expended from year to year, a feature which may be detrimental to successfully managing the resource for maximum yield.

So far, I have discussed a hunting type of fishery in which fish schools and school groups are contagiously distributed and in which effort units are dependent on each other and on the success of previous effort units. In fisheries which cover a vast range, where it is not possible for an effort unit to reach more than a small part of the range in a day, the efficiency of a unit of effort would not increase as rapidly relative to a declining fish population. The California based tropical tuna fishery, for example, covers a very large range; boat trips last weeks, units of effort are spread out, and the effect of communication on efficiency is much less. The advantage of fishing in specific areas where you found fish the previous trip is also less than in the sardine fishery.

In a trawl fishery, where the unit of gear catches a percentage of what is in the swath, and where a catch-per-standard-drag can be related to some degree to the total area of the fishing ground, these effects may not be so pronounced. In this case, unless the fish tended to concentrate, the efficiency of effort on a declining population would not increase as dramatically as in a purse seine fishery. Nevertheless, the factors I have mentioned would still be in effect to some degree.

In some ways, it is unfortunate that most simplistic models have worked so well with the North Sea plaice fishery. This has probably deterred investigation of the assumptions used in these models, and encouraged the use of the assumptions in totally different fisheries, where they may lead to conclusions which are grossly in error.

The conclusion that the catchability coefficient is a variable doesn't preclude use of catch-per-effort data obtained from the commercial fishery, but it certainly casts doubt on the validity of some fish population models which use such data. One way of avoiding this major problem is to obtain return-per-effort data from a survey which is independent of the fishery--one which may be designed to sample throughout the distribution of the fish in a statistically valid manner. These data may be more scanty, and consequently more variable, but would not suffer from the bias inherent in catch-per-effort data obtained from the commercial fleet. In some types of fisheries, where the fish are not searched after but are attracted to the fishermen by bait, chumming, night light, or some other means, there is a different set of factors operating. A discussion of those problems is beyond the scope of this present paper.

In summary, I contend that, contrary to common use, catch-per-effort is not linearly related to fish population size; that the catchability coefficient is not a constant, but instead it is a variable which is inversely related to fish population size. Furthermore, the rate of change of the catchability coefficient relative to population size is dependent on the nature of the specific fishery in question.