CATCH-PER-UNIT-OF-EFFORT: FACT, FICTION, OR DOGMA

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I assumed this symposium is entitled FISHERY SCIENCE: Fact, Fiction, and Dogma, by Isaacs, Radovich, and Rothschild, respectively. This seems quite appropriate since I lay no claim to being a population dynamicist.

In the sense that every angler is an expert in fishery science, every hunter an expert in wildlife management, and every citizen an expert in politics, I will comment, expertly, on what is wrong with using catch-per-effort to solve fish population problems.

One of the greatest problems with fishery science is that concepts developed by certain population dynamicists get set in concrete. We tend to forget that a mathematical model of a fish population is something that you put on paper, on a blackboard, or in a computer, and is not a precise description of a real and complex biological phenomenon, no matter how hard we wish it to be. Biological phenomena are too difficult to model; too many variables affect them to even enumerate—let alone describe. I am not saying that models are not useful, but that their use can be a handicap if we forget what they really are.

Population models are built upon assumptions. We assume that the phenomena in which we are interested can be described by an equation; that variables, which are too many and too complicated to be understood, vary randomly and can be regarded as background noise; that certain factors are constants, even though in nature they may not be, because the solution of the problem requires that they be constants; and when we solve our problem on the blackboard or in a computer, we are surprised when the fishery, whose data we have used, behaves differently from our solution. Considering the complexities in nature, it probably should be more surprising if the fishery followed our model.

The real test of a model, of course, is how well it predicts, not whether or not we use biological sounding terms to describe its coefficients and exponents. If it doesn't work, something is wrong either with the mathematics, the assumptions, or the data. Population dynamicists usually blame the data, or occasionally the animal itself for not behaving in a predictable manner.

Let us take a hard look at some assumptions usually made in most fisheries calculations. I suppose that we can begin with Baranov who published his two famous papers in Moscow in 1916 and 1926.

He assumed in his model that fish are distributed evenly over the bottom of the fishing area, and that his unit of gear, a trawl, takes a constant proportion of fish within the swath of the trawl. The percentage of fish caught within the swath times the ratio of that swath to the total area is what he calls "elemental fishing intensity". His "real elemental fishing intensity" represents a constant proportion of the fish population. This assumption, and others he made or inferred, such as uniform distribution of fish over the area, has persisted in the proliferation of fisheries' models. Since that time, there has been little attempt to confirm or test these assumptions, or even examine them closely. Many authors, such as Schaefer (1954), state the assumption that a unit of gear catches a constant proportion of the fishable population. Even though it is not stated, it is implicit in almost all fisheries models. This assumption implies three other assumptions which may not always be stated: (1) fish are distributed uniformly over the fishing area, (2) effort is distributed randomly over the fishing area, and (3) each unit of effort is independent.

Since none of these three assumptions are met in most fisheries, the assumption that a linear relationship exists between catch-per-effort and population size is usually incorrect. Most authors recognize that deviations from these assumptions exist, but generally regard such variations as random noise. However, there are many reasons for believing this is not so. It is my contention that *a given unit of fishing effort takes an increasingly larger proportion of the fish poulation 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, of course, 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 depends more 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: (1) any usable unit 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 relates in some way to effort expended by man; (2) many species of fish tend to school up in certain areas more often than in others; and (3) effort units are not independent since fishermen tend to fish in areas where they had previously caught fish and they communicate with each other.

Let me give an example. When the sardine fishery began off the coast of California, the sardine population was very large, and fish were caught quickly, easily, and close to port. Catches tended to saturate gear, making it difficult to determine different population levels on the basis of catch-per-effort. Some decline in the sardine population had to occur before any change in the catch-per-effort could be noticed. Of course, it is well recognized that, at high fish population concentrations, limited plant capacities result in boat limits which affect catch-per-effort, and adjustments can be made for this effort. However, common usage implies that below that level, catch-per-effort is linearly related to population size.

As the sardine population became smaller, it was obvious to fishermen that the fish were not distributed randomly over the fishing area. Schools tended to cluster, usually in certain areas more often than in others. Therefore, fishermen searched in a nonrandom manner. They searched where their experience revealed sardines were more apt to be found, 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 learn 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 radio, the entire fleet becomes alerted to where fish are being caught. This allows the fleet to converge on groups of schools so that fishermen can make better catches than if they fished independently and searched randomly for fish which were randomly distributed. In addition, 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 canneries each morning.

As fish became scarcer, dependence continually increased on communication, radio, and echo sounders. At low population levels, eventually airplanes were used to locate fish and even help fishermen set their nets around schools. All of these factors—communication, clustering of fish schools, intelligent and nonrandom behavior of 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. Reliance on communication is a function of need which is related to the scarcity of fish. At higher population levels, communication becomes more of a social device than economic necessity.

Since the fisherman is interested in maximizing his profit, he does not expend his effort to randomly sample the population in order to find out where fish are scarce, as well as where they are abundant. Instead, he fishes in areas where his probability of success is the greatest. If we were starting out now to design a survey to determine the abundance of fish off the coast, we would have a difficult time 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, should cause the catchability coefficient to increase continuously as the fish population declines. Therefore, if a fish population is overfished by too great an expenditure of effort, the catch should not come to an equilibrium at that effort 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, and so does the Pacific mackerel fishery.

Richard H. Parrish (1974) has shown that the rate of exploitation of poor year-classes of Pacific mackerel off California is higher than that of strong year-classes. This is precisely what should be expected in a purse seine fishery with the characteristics of the Pacific mackerel fishery.

Schaaf and Huntsman (1972) say:

"Also we suspect that Menhaden are disproportionately more vulnerable when the population is small. While this hypothesis is unprovable with present data, the phenomenon could easily result from density-related behavior changes.

So for several reasons, despite an overall decrease in the number of effort units, fishing mortality has not decreased proportionately."

Bernard Skud of the International Pacific Halibut Commission (person. comm.) has indicated:

"Some of the Commission's earlier work also suggested a change in the relationship between CPUE and population size at lower stock densities, but the matter was not pursued very extensively. With our recent review of catch and effort data, we have been questioning some of the conclusions concerning halibut stocks and their management."

In a personal communication from John Gulland of the Food and Agriculture Organization, on this subject, he commented:

"We are not quite sure what the present situation in Peru is but there is a nasty feeling in the back of people's minds that although the catch per boat, catch per set, or other catch per nominal effort, has stayed put until very recently, there may have been a serious but concealed decline in the stock. I know, in fact, that some people are beginning to be very wary of using any catch per unit effort data in a purse seine fishery and are hoping to use something independent of the fishery such as acoustic surveys by research vessels."

New innovations which tend to increase efficiency usually are adopted over a period of time. These changes in a fishery are usually analyzed and catch data are corrected. Once adopted, most of these innovations are considered to be fully in effect from then on, and 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. This, of course, introduces another level of complexity into the problem.

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 in relation to effort is valid—that the catch will come to some equilibrium at any expenditure of effort. Certain of these economic models also require a stability of effort expended from year to year, a feature which may make the successful management of the resource for maximum yield difficult.

So far, the discussion has referred to a hunting type of fishery in which fish schools and school groups are contagiously distributed, in which effort units are dependent on each other and on the success of previous effort units, and in which mobility of effort over the fishing area is high. In fisheries which cover a vast range, where an effort unit cannot reach more than a small part of the range in a day, the increase in efficiency of a unit of effort in a declining fish population would be less. 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 than in the sardine fishery. The advantage of fishing in specific areas where you found fish the previous trip also is less.

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 be even less. 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, these factors would still be in effect to some degree.

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

The hypothesis 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 assume it is a constant. A way of avoiding this major problem, as Gulland suggested, 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 fish distribution in some statistically valid manner. These data would 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 discussing these ideas with population dynamicists, I find that in general they contend there is really nothing wrong with the models since an assumption of the model states that fishing mortality is proportional to what they call the "real fishing effort." They seem to be aware of these problems, but their publications rarely give a hint of such an awareness, and consequently "general practitioners" attempt to apply these models in situations where they cannot possibly fit.

Population dynamicists feel the problem with which we are faced is whether the units of fishing effort that we customarily use, such as number of nights fishing, number of purse-seine sets, and so forth, and which they call "nominal fishing effort", are a good measure of what they refer to as "true" or "real" fishing effort, or whether "nominal units of effort" become more efficient as the stock declines.

I am not saying this is a real "cop-out", but let us look at the population dynamicist's definitions: "real" or "true" fishing effort is that factor which he has on paper, the blackboard, or in the computer (at best, it should be called "theoretical effort"). On the other hand, the value you get from the fishery such as catch-per-days absence, catch-per-standard-drag, and catch-per-angler-day are not "true" or "real" but only "nominal effort." The inference here is that to the dynamicist, reality exists in the model and not in the world. This, I feel, is the crux of our problem.

There are a few other dogma that I would like to attack but these will have to await another meeting.

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