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Stock Discrimination in Marine Fishes

by

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ABSTRACT

Various methods of stock discrimination in marine fishes were reviewed, especially tagging and migration studies, meristics, parasites, serology, and biochemical-genetic differences obtained by electrophoresis, with particular attention to cod of the Northwest Atlantic. The advantages and disadvantages of these methods for stock discrimination were noted and also principles regarding the use of these and other methods on natural fish populations. The conditions leading to stock formation, especially of large stocks, were discussed and an illustration given of the uses of stock concepts for management and their inherent dangers.

INTRODUCTION

When Dr. Iles asked me to give the opening paper to this symposium, I rashly accepted, although, apart from a contribution in 1975 (Templeman, 1976) to the committee which was considering Flemish Cap as a region for research on year-class recruitment of cod and redfish, I have not attended a meeting of ICNAF or NAFO or its committees since 1971. Although this is my first attendance at a NAFO meeting, I am part of the history of ICNAF, having signed the original ICNAF Convention in Washington in February, 1949 on behalf of Newfoundland, was a member of the committees that decided the statistical divisions of ICNAF, with John Gulland in 1965 (Templeman and Gulland, 1965) recommended to ICNAF the quota system which is now the main basis for control of catch and effort by NAFO, and took part in the gradual unfolding of research knowledge on fish biology and stock discrimination in the area.

It is inevitable that I shall lean heavily on personal knowledge of cod stocks and that, since this is an overview paper, I shall introduce some of the subjects and ideas to be presented in more detail by others. Only a small part of the great volume of literature on stocks of marine fishes can be mentioned, with a major bias toward Atlantic cod (Gadus morhua), especially of the Northwest Atlantic, as examples to illustrate and provide commentary on the major methods used to discriminate between fish stocks and to try to keep some measure of uniformity in this paper.

STOCKS

There have been many definitions of stocks (variously called population units, management units, unit stocks) most of them not differing greatly. Templeman (1979) gave the following definitions which can serve as a point of departure: A population is a group of fish occupying an area at a particular time; a stock is a recognizable unit which has certain area-occupying and migratory patterns but whose spawning is separate from those of other stocks; a stock complex is a recognizable group of adjacent stocks which at periods other than spawning intermingle or overlap greatly and are different in migratory behavior from adjacent stocks or stock complexes. The primary location base of a stock is its spawning area, where the mature spawning fish of the stock are largely separated from other stocks of mature fish of same species spawning at the same time.

Marr (1957) defines a population unit as a fraction of a population that is itself self-sustaining. In Parrish (1964) a unit stock is defined as a relatively homogeneous and self-contained population, whose losses by emigration and accessions by immigration, if any, are negligible in relation to the rates of growth and mortality.

Ideally (Cushing, 1973), (a) the stock should be isolated, (b) it should suffer neither loss by emigration or gain by immigration (the loss by emigration can be disregarded if it is not too large). (c) mating within it should be randomly distributed.

Cross and Payne (1978), from the biochemical-genetic viewpoint, define a fish stock as a panmictic group of individuals that share a common gene pool, and that are more or less isolated during the reproductive period from all other conspecific populations. Such stocks may be distinguished by investigating the geographic distribution of allelomorphic genes over the species ranges.

The characters used for differentiation between management units need not necessarily be genotypic and unaffected by environmental influences, and some of the management units may not even have diverged sufficiently to produce differences in the genotype (Parrish, 1964).

PRINCIPAL METHODS OF STOCK DISCRIMINATION

Attempts at stock discrimination in marine fishes principally involve tagging and migration studies, meristics, parasites, serological and biochemical-genetic information. Many other methods, some of which will be mentioned later, are also used to provide information on differences between populations or stocks.

TAGGING AND MIGRATION

The most generally used preliminary method of stock discrimination has been tagging and migration studies, as illustrated for the Arcto-Norwegian cod stock by Trout (1957), for the Icelandic cod by Tåning (1937), for the cod stocks of the Newfoundland and some adjacent areas by Thompson (1943), Templeman and Fleming (1962), Postolaky (1966), Templeman (1974, 1979), for the Canadian Maritimes by McKenzie (1956), the southern Gulf of St. Lawrence and northern Gulf stocks by Martin and Jean (1964), and by Wise (1958, 1963), for the southernmost cod stocks of the western Atlantic.

MERISTIC COUNTS

Since Heincke (1898) attempted to use meristic numbers to distinguish between various races of herring, meristic numbers, especially vertebral and fin-ray counts but also gill-raker and scale counts, have been used as aids in distinguishing fish stocks.

Schmidt (1930) used vertebral and dorsal fin-ray means to distinguish between cod from various parts of the North Atlantic. Since that time vertebral counts were found useful in distinguishing cod stocks at West Greenland (Hansen, 1949; Templeman, 1962). For the Newfoundland area, Templeman (1981) found enough distinction in vertebral means and in high and low vertebral numbers to distinguish the cod of West Greenland from those of Labrador, and to distinguish the Labrador-East Newfoundland stock from the northern Gulf and the southern Grand Bank stocks and the stocks of the Avalon stock complex. McKenzie and Smith (1955) found differences in vertebral means of cod off the Canadian

Maritimes and McKenzie (1940) reported lower vertebral means for autumn spawning cod off Halifax and vicinity compared with means for spring spawners.

PARASITES AS INDICATORS OF FISH STOCKS

Parasites may be useful as migration and stock tags when the source and site of the infection are known and the parasite has a sufficiently long life, and especially when infection by the parasite occurs on a spawning ground or in a spawning river. The latter was illustrated by Margolis (1963) where of more than 50 species of mainly metazoan parasites found to occur in sockeye salmon, only two, Triaenophorus crassus, a cestode whose infection of young sockeye occurred in western Alaskan river systems, and Dacnitus, a nematode whose infection of young sockeye occurred in some Asian river systems, proved to be subsequently useful for separating these stocks of sockeye in the sea.

In Templeman et al. (1957), for the cod nematode Phocanema (Porrocaecum) decipiens whose infection of cod in eastern Newfoundland waters occurred inshore, and Templeman et al. (1976), where infection of cod by Lernaeocera branchialis occurred mainly inshore, the parasite numbers were indicative of the extent and degree of inshore and offshore migration but were of assistance in defining the Flemish Cap cod as a separate offshore stock.

Khan et al. (1980) used the protozoan, Trypanosoma murmanensis, a parasite of cod blood transmitted by a leech, Johanssonia arctica, which lives in very cold water. Infections by this parasite were consequently of considerable use in discriminating broadly between cold-water and warmer-water cod stocks. Because the areas of infection are not precisely known, there were difficulties of argument in areas with intermingling cod stocks such as Div. 3L. Immatures of the northern stock, growing up in southern areas, which may when mature become more highly infected on a more northern spawning ground also offer difficulties of interpretation.

SEROLOGICAL AND BIOCHEMICAL METHODS

Introduction. The serological data and the results of biochemical-genetic studies by electrophoresis on various proteins have the advantage that often it can be demonstrated that the patterns are inherited in simple Mendelian ratios. In a sample of fish of a particular stock, two alleles A and B should be present in the ratios of AA: 2AB: BB as postulated by the Hardy-Weinberg law or equilibrium (sometimes called the Castle-Hardy-Weinberg, or C-H-W, law or equilibrium from Castle, 1903; Hardy, 1908; Weinberg, 1908). Agreement with the Hardy-Weinberg law indicates a separate stock, significant disagreement, an excess of homozygotes, indicates a mixture of stocks. The regions of relative stock purity and of intermingling can be located if there is enough difference in the proportions of the two or more alleles in the adjacent stocks. Also, differences between populations or stocks can be tested for significance by comparing gene frequencies by contingency tables and the resulting chi-square values.

Serological Studies. There have been many studies of blood groups in fishes, as for example those of Møller (1966a, 1967, 1968) on cod. Møller found that the data for two blood groups agreed with their control by allelic genes and that the Arcto-Norwegian and coastal cod stocks off Norway, distinguished by otolith type, showed differences in two blood groups, the ranges being well separated in one of the groups.

Biochemical-genetic studies. The most useful and most extensively used protein systems examined by electrophoresis for separating cod populations have been haemoglobin polymorphism and blood serum transferrins. There are three main genotypic patterns of haemoglobin polymorphism from a pair of different allelic genes. The proportions of these patterns have been very useful in showing differences in cod populations and stocks of the eastern and north-central Atlantic (Frydenberg *et al.*, 1965; Sick, 1965a, b; Jamieson, 1968), but not in the North American area in Jamieson (1975) following the possibility of small differences suggested in Sick (1965b) and Odense *et al.* (MS 1966). Blood serum transferrins have been found useful for separating cod populations in the major regions of the North Atlantic (Møller, 1962a, b; 1968; Jamieson, 1968, 1975; Cross and Payne, 1978; Jamieson and Turner, 1979). Transferrins offer much genetic polymorphism from a series of nine co-dominant alleles at the genetic locus (Jamieson and Johnson, 1971). Some of these are rare mutations. In Jamieson's (1975) studies of 11 populations of North American cod there were six transferrin (T_f) alleles, giving the possibility of 21 genotypes (6 homozygotes and 15 heterozygotes) of which 20 were noted. Cross and Payne (1978) also interpreted their transferrin polymorphism studies on Northwest Atlantic cod in terms of six alleles segregating at a single locus.

Among the additional proteins investigated for polymorphism in the Atlantic cod were: general serum proteins (Ullrich 1967, 1968), and enzymes such as esterase (Nyman, 1965; Jamieson, 1975), lactate dehydrogenase (Odense et al., MS 1961, 1969; Jamieson, 1975), and phosphoglucose isomerase (Dando, 1974; Cross and Payne, 1978). These also gave useful results for separating some cod populations. See also de Ligny (1969) for a review.

ADDITIONAL METHODS OF STOCK DISCRIMINATION

Among the other methods that have been used in attempts to discriminate between fish populations and stocks, and a few examples of their use, especially for cod, are: differences in growth and sexual maturity of cod (Fleming, 1960); differences in or due to spawning period, especially useful for herring (Johansen, 1924; Cushing, 1967; Hodder and Parsons, 1971; Parsons, 1972) but also to some degree for cod (McKenzie, 1940; Templeman, 1979); differences in color of cod (Dannevig, 1953; Love, 1970, 1974); evidence from otolith structure, used to differentiate between Arcto-Norwegian and coastal cod (Rollefsen, 1933; Trout, 1958); differences in weight and size of otoliths (Templeman and Squires, 1956, for haddock; Rojo, 1977, for cod); differences in scale circuli (Thompson, 1943, for the first year zone of cod scales; Lear and Sandeman, 1979, for salmon): discriminant function analyses using meristics or body proportions or both (Amos et al., 1963, for pink salmon; Parsons, 1972, for Canadian Atlantic herring; Sharp et al., 1978 for Canadian Atlantic capelin); correlation or lack of correlation between recruiting year-classes of different stocks (Cushing, 1973). There are great numbers of references to the above, only a few of which and especially for the northern part of the Northwest Atlantic have been used for illustration.

DISCUSSION AND CONCLUSIONS

A marine fish stock is a recognizable population unit for management purposes with its own spawning areas or spawning time or segregation for spawning, and egg and larval drift or larval drift and migration patterns made possible by a water current system. It may be genetically different from an adjacent stock if the barriers to migration of adults and drifts of larvae, and the lack of intermingling at spawning time are great enough. The degree of genetic difference is an indication of the length of the period of stock separation. The following discussion refers especially to cod of the Northwest Atlantic.

COMPARATIVE RESULTS FROM DIFFERENT TECHNIQUES

Tagging and migration studies form the primary attack on stock discrimination. Their success depends on an adequate level of fishing pressure throughout the area investigated, to provide the opportunities for recapture, and an adequate success in return of tags and recapture information. Adequate tagging should be carried out in spawning season on different parts of the spawning grounds of adjacent stocks and in feeding season in the nursery and feeding areas between them. Also, tagging needs to to be done in wintering areas when these are separate from the spawning areas.

Meristic differences may be present and useful when there are enough differences in spawning times and temperatures to produce them, and in these cases, also, the extreme numbers in a frequency can be used as tags, being absent or very scarce in a stock and the reverse in an adjacent stock. Also, if egg development after spawning of one stock is in winter or early spring with low or stable water temperatures, or in an area such as Flemish Cap where there is little variation in temperature during egg development, variances of the meristic frequencies affected by temperature will be small compared with those of adjacent stocks spawning later in the year with more variable temperatures during the period of egg development. There may also be genetic factors operating to take part in the production of meristic differences (Hempel and Blaxter, 1961).

Parasites are useful as indicators of fish movements when the parasite lives long enough and when the source of infection is known, and especially for stock discrimination in the rare cases in the sea where the main source of infection is on the spawning ground of a stock, but not, or in much lesser degree, on the spawning grounds of adjacent stocks.

The biochemical-genetic studies thus far, on cod populations of the western Atlantic, have shown great genetic distinctions between main areas, such as: West Greenland and Labrador, cod from north and south of the Laurentian Channel, and especially between Flemish Cap and the adjacent Grand Bank. These are areas with deepwater channels separating them, and in some cases distance and current direction restricting movement of eggs and larvae between areas. That the cod populations of these areas were essentially separate was already known from migration and meristic and sometimes parasite studies; but the large genetic differences are useful to indicate how long the populations have been essentially separate. Apart from the above, although differences between samples may readily be found, the biochemical-genetic sampling has not been extensive enough and has depended too much on chance sampling to offer much assistance in separating cod stocks of the western Atlantic. In the nursery and feeding areas, there are difficulties as for meristics and parasite infections and there can be significant biochemical-genetic differences between the cod of the spawning area and of the feeding or overwintering areas, and yet not have separate stocks. There may be a mixture of stocks in the feeding or overwintering areas, but for the biochemical-genetic method, comparisons with the Hardy-Weinberg law may produce evidence that they are mixtures of more than one stock.

GENERAL PRINCIPLES IN USING STOCK DISCRIMINATING METHODS

Remembering that the home base of a stock is the mature stock on the spawning ground at spawning time, one must of course ensure that the investigation, by whatever method, investigates the mature stock at spawning time. For large stocks of pelagic spawners such as the cod this is often a difficult task. The spawning grounds of the Labrador-East Newfoundland cod stock or stock complex are about 800 nautical miles in length from north to south (Templeman, 1981). Although it has been convenient to consider this group as one stock, one would expect to find some differences between cod spawners in various parts of this vast spawning area. The more northern coastal populations of this stock are more related to more northern spawning grounds than are the southern coastal populations of the stock (Templeman, 1979). In cod tagging and other stock discrimination studies, it must be remembered that not all mature cod spawn in the area of the spawning ground where they are caught and tagged or sampled. The spawning of cod in the spawning area of the Labrador-East Newfoundland cod stock proceeds for several months, and within this time many cod spawning earlier much farther northward can return rapidly as spent fish to more southern spawning areas of the stock (Postolaky, 1966). It is essential therefore, when possible, to note the condition of the gonad with regard to sex, sexual maturity, and spawning. This is not readily done in tagging except for fish with running eggs and milt but are essential data for other studies. Apart from immatures whose nursery area is the spawning ground but are not necessarily of the same stock as the spawning fish, immatures of marine fish from nursery areas remote from the spawning ground will not usually have visited the spawning ground except possibly for large immatues. Trout (1957) found that a "dummy" run of large immatures migrated with the Arcto-Norwegian cod toward the spawning ground but to a lesser distance.

In using parasites, meristics, serological, or biochemical-genetic methods to discriminate between stocks, one should keep in mind other information regarding stocks such as migration or other stock-discriminating studies. One must be wary in using differences in infestation of immature fish with parasites, or such environmentally-affected parameters as growth, or size at sexual maturity in feeding and nursery areas as evidences of differences between stocks, as the stock identification of immature fish from these areas may be doubtful. Immature fish from many nursery areas may, when mature, intermingle on the spawning grounds of a stock.

After spawning, the spent cod proceed to feeding grounds which are apparently (Templeman, 1979) usually close to the areas where they existed as immatures. Again, the fish sampled in the feeding areas for biochemical or other methods should have size, sex, and gonad condition recorded. Age is useful, at least in parasite studies. A usual weakness of tagging in the feeding and nursery areas is the lack of information on the stage of maturity of the individual fish in the overlapping of the immature and mature sizes.

Fish sizes should always be taken and where possible age. Apart from the possibility of changes in biochemical indicators with size and age, the small and the large fish in a feeding area may on the average be from different stocks, e.g. in Odense et al. (MS 1966, 1969) the St. John's, Newfoundland cod sample showed a marked deviation from the Hardy-Weinberg law, indicating the presence of more than one stock. Templeman (1979) reported that the smaller cod from the St. John's area were predominantly high-vertebral-count fish from the northern (Labrador-East Newfoundland) stock, whereas the large cod, which lie deeper, were mostly lower-vertebral-count fish of more southern stocks.

Growth and size at sexual maturity, year-class differences, otolith, scale, morphometric and similar researches are best applied in the preliminary studies to spawning cod on the spawning grounds. In a stock, such as the Labrador-East Newfoundland cod stock, with apparent egg and larval drifts of 600 nautical miles or more, cod on nursery grounds, belonging to the same stock can exhibit different growth and age at maturity and parasite patterns (See Fleming, 1960 for cod of the area included for the Labrador -East Newfoundland stock by Templeman, 1962, 1979, 1981).

DETERMINATION OF STOCKS

Stocks of cod and other marine fishes are made possible by appropriate current, temperature and salinity conditions, spawning times and spawning areas, accompanied by suitable quantities and varieties of larval and adult food and nursery areas for the young. The maturing adults in the nursery areas must have the current and other stimulation and swimming and energy abilities to reverse the direction and distance of the egg and larval or larval drift and reach the spawning grounds. Iles and Sinclair (1982) related the existence and size of herring stocks of the North Atlantic to oceanographic conditions resulting in larval retention areas of various sizes. For the Arcto-Norwegian cod stock, spawning at Lofoten and vicinity, the long drift northward over cold conditions and relatively deep water for settling of the larvae allow a very large nursery area for the stock. Similarly for the Labrador-East Newfoundland cod stock, the large spawning area and the low upper water layer temperatures at spawning time in March-May (mainly March-April) with the consequently slow hatching and larval growth and the southward moving Labrador current, enable the larvae from this stock to settle over a very large area (Templeman, 1979, 1981). For three Northeast Atlantic cod stocks spawning in March, the North Sea cod settle to the bottom in early July at about 3.5 cm, Icelandic cod in early August at about 4.5 cm, and Arcto-Norwegian cod settle in the Barents Sea in late August and in September at about 7.5 cm, the larvae drifting in the coldest water and fry settling in the deepest areas having the largest pelagic life and consequently being more widely dispersed (Corlett, 1958). Naturally, smaller cod stocks, also, are only possible under conditions of larval retention by oceanographic conditions, which occur in a smaller retention area such as that produced by the eddy system around Flemish Cap (Templeman, 1976; Kudlo and Boytsov, 1978; Borovkov and Kudlo, 1980).

USE OF STOCK CONCEPTS FOR MANAGEMENT AND AN EXAMPLE OF THE INHERENT DIFFICULTIES

The application of assessments to stocks of cod and other species in the NAFO area is very much limited by the statistical division units which provide basic data, and hence the assessments and resulting quotas or TACs are often not finely tuned, even in relation to available information on stocks. To take the Labrador-East Newfoundland cod stock as an example, quotas for the northern part of the stock in Div. 2GH and for Div. 2J,3KL are established separately. In such a stock it might be expected that cod from the northern extremity of the stock or its stocklets could on the average have less larval survival than those farther south and thus be quickly damaged by overfishing. This apparently occurred in the part of the stock in Div. 2GH through overfishing in 1965-69 (May et al., MS 1981, table 3). Hence, the wisdom of separate and small quotas for the northern part of the stock which should be watched carefully and possibly not fished at all except in the tiny coastal fishery. The southern part of the stock in Div. 3L intermingles greatly with several other cod stocks (Templeman, 1979, 1981). In such a very large stock or stock complex as the Labrador-East Newfoundland stock, cod spawning farther south are related to more southern nursery and feeding areas (Templeman, 1979). Under the ice conditions sometimes prevailing, a quota for Div. 2J, 3KL may be largely taken in the southern divisions if there is ice cover or lack of cod in the northern divisions, with correspondingly greater reduction of the stock in the more southern coastal areas. In years when fishing is possible in the north in winter-spring and cod are abundant there, the cod are so concentrated by water temperatures that trawlers may concentrate in the north, and this apparently happened in the early fishery with greater effects on the coastal populations of cod of the Labrador and northeastern Newfoundland than in Div. 3L. Consideration should be given to imposing quotas for cod in individual divisions of Div. 2J, 3KL.

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