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Population Structure and Management Units of Redfishes (Sebastes sp.)

on the Scotian Shelf

by

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## ABSTRACT

The nature of a fish "stock" is discussed with reference to redfish. The population structure of redfishes of the Scotian Shelf is described, using morphological, electrophoretic, and distributional data. It is shown that a reproductively isolated unit is not an appropriate one for management. Appropriate management units are suggested.

## INTRODUCTION

Fisheries management, in the Northwest Atlantic and elsewhere, is founded on the "stock concept": the idea that all fish (of commercial importance) can be arranged into "stocks". "Stocks" are supposed to have unique biological attributes and to be ideal groups for assessment and management. Despite the fundamental importance of this concept, the nature of a "stock" is poorly understood and indeed the word is used for several quite distinct meanings. For instance, Ricker (1975) defined a "stock" as a completely arbitrary management unit, whereas ICNAF, ICES, and FAO adopted a definition which is purely biological and approximates to a deme (Anon., 1960).

Furthermore, the use of any detailed biological definition for this term presupposes that the defined groups of fish occur. There are undoubtedly cases in which some fishes conform to present stock concepts (e.g. Pacific salmons, Ricker, 1972; North Sea herring, Cushing, 1975, 1980). Equally, there are many fish that do not conform in various ways. These include witch flounder (Fairbairn, 1981; Bowering and Misra, 1982), summer flounder (Smith, 1973) and Gulf of St. Lawrence herring (Ware and Hendriksen, 1978) as well as the redfish discussed in this paper and the great majority of "shellfish" species. In these cases, the fish populations appear to have a more complex structure than the one implied by the "stock concept".

I therefore suggest a new terminology which simplifies discussion of these structures and their relationships to fisheries management. Because the word "stock" has been used with so many meanings and because it is currently used with specific meanings by various management agencies, it is avoided in this paper. Its replacements are:

"Management Unit": A group of fish, of one or more species, that are managed as a single unit.

STOCK DISCRIMINATION SYMPOSIUM

- "Assessment Unit": A group of fish that are assessed as a unit. The assessment unit will usually correspond to the management unit, but where biologically-distant groups are exploited together, two or more assessment units could be combined into one management unit.
- "Population Unit": Any group of fish which has some biological reality. Species, demes, single year-classes within a deme, and elementary populations (Lebedev, 1967) are all population units. A year-class of several species combined is <u>not</u> a population unit.

This definition of a population unit is deliberately broad. However, it is generally observed that they are arranged in (usually hierarchical) structures. Hence:

"Population Structure": The arrangement of population units in the population. (Where a "population" includes all species inhabiting a given area.)

This latter term has been used before. Fisheries biologists have generally used it for "age structure of the population", while population geneticists have used it for "genetic structure of the population". Both of these meanings are included in the above definition.

The task of determining "stocks" becomes one of selecting appropriate population units, which fit the assumptions of the assessment models. These assessment units must yield management advice that can be applied to management units that are appropriate to the fishery.

This paper attempts to apply these concepts to the redfishes of the Scotian Shelf (NAFO Divisions 4VWX). It is primarily based on a review of previously published studies, with the addition of some new data. It is necessarily discursive, and even speculative, since the data needed to answer several important questions are lacking.

#### **REDFISH POPULATION STRUCTURE**

#### Taxonomy and Occurence of Species

The redfishes comprise the genus <u>Sebastes</u>. Three species are presently recognized in the northwest <u>Atlantic</u>: <u>S. marinus</u>, <u>S. mentella</u>, and <u>S. fasciatus</u> (Robins <u>et al.</u>, 1980). The distinction between the first pair is now generally accepted. The separation of <u>S. mentella</u> and <u>S. fasciatus</u> has been supported on phenotypic grounds by Barsukov (1968, 1972), Barsukov and Zakharov (1972), Templeman (1980) and Ni (1981a, d). Kenchington (in prep.) has questionned this conclusion, and has shown that, on the Scotian Shelf, a range of meristic and morphometric characters of the two groups overlap. However, preliminary electrophoretic work by McGlade <u>et al.</u> (in prep.) suggests that these groups are sufficiently genetically different to represent subspecies or even species.

Thus, it appears that there are three distinct gene pools amongst these redfishes. For convenience, they will be refered to as species although this status may not be fully justified.

Kenchington (1980, in prep.) and Ni (1981b, c) have shown that S. fasciatus is the predominate species on the Scotian Shelf, while <u>S. mentella</u> is mixed with it along the continental slope. Anal fin ray counts are the best single external character for separating these species (Ni, 1981a). Ni's (1981b) values for this character suggest that S. fasciatus is found as deep as 600 metres in these Divisions, while <u>S. mentella</u> does not occur above 300 metres. Data from various surveys, examined by the author, support these depth ranges.

S. marinus is rare on the Scotian Shelf. The only confirmed specimens were collected by the author at the easternmost tip of Banquereau Bank during a recent cruise. For fisheries management purposes, this species can be ignored.

## Adult Distribution

The distribution of <u>S. fasciatus</u> on the Scotian Shelf is best represented by the data from noutine July groundfish surveys (Halliday and Kohler, 1971). Scott (1976, 1981) has published charts of these data, from which figure 1 is derived. More detailed analyses have been presented by Clay (1980) and Scott (1981). Unfortunately, the surveys do not include inshore or rough bottom areas, and do not extend below 200 fathoms (365 metres). <u>S. fasciatus</u> does occur in small numbers in very shallow water (less than 10 metres) near Nova Scotia (pers. observation). It may be abundant over rough bottom. Clay (1980) reported considerable redfish catches at depths of about 350 metres, and a recent cruise suggests that they may be abundant at greater depths, at least in the eastern part of the area (Zwanenburg, 1982).

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In summary, the summer distribution appears to be as follows: <u>Sebastes fasciatus</u> occurs all across the Scotian Shelf with <u>concentrations in most of the</u> deeper areas. It is abundent along the edge of the Laurentian Channel and in the basins of the Fundian Channel. Uncertain numbers occur along the Continental Slope down to at least 600 metres depth. <u>S. mentella</u> occurs only below 300 metres along the slope, and perhaps at <u>similar</u> depths along the edge of the Laurentian Channel.

#### Adult Movements

Commercial fishermen generally regard redfish in this area as nonmigratory; a view that has been accepted by most authors. Because of swimbladder expansion and other problems, it is not practical to tag offshore redfish and so indirect evidence must be used to study this question.

Tags have been successfully applied to an inshore population (perhaps a distinct subspecies; <u>S. fasciatus kellyi</u> Litvinenko) at Eastport, Maine (Kelly and Barker, 1961, 1963), and to <u>Sebastes</u> sp. juveniles in Godthab Fjord, Greenland (Hansen, 1961, 1964). In the Pacific Ocean, various inshore <u>Sebastes</u> have been tagged (e.g. Frey, 1971; Carlson and Haight, 1972; Love, 1980; Larson, 1980). In all of these studies exceptionally little movement was observed (on the order of no movement between sites 1 to 10 km apart). Carlson and Haight (1972 tagged <u>S. flavidus</u> from one site and released them up to 35 km away. 45.9% of those displaced along the coast were recaptured at the home site, while none of these were taken elsewhere. This was interpreted as ademonstration of active homing.

The relevance of these results to offshore <u>Sebastes</u> is uncertain. Some evidence for annual migrations of Pacific <u>species</u> is available. Gunderson (1971, 1977) and Love (1981) detected some changes in catch per unit effort which indicated movements. The former found considerable seasonal depth changes, but these could be explained by horizontal movements of less than 20 km (Gunderson, 1971). Love (1981) did not estimate distances moved. The only evidence for seasonal lateral migrations by Atlantic redfish concerns the Barents sea population (Sorokin, 1961; Travin, 1961). This is again based on the distribution of the fishery, but neither author presents sufficient data to allow their conclusions to be checked.

Thus, it seems likely that the annual migrations of Scotian Shelf redfish are extremely limited. Some test of this hypothesis is possible by comparing the catches of spring, July, and fall groundfish surveys. Unfortunately, there are many problems with these data including: a very strong skew (Kenchington, 1981), the use of a different ship and net in July from those used in spring and fall, incomplete coverage of the depth range, incomplete areal coverage in spring and fall, seasonal variations in vertical migration being compounded with horizontal movements, a lack of species, sex, and age data, and the short time series of spring and fall surveys. In the face of these difficulties, no rigorous statistical analysis has been attempted. Instead, for each year of the July surveys (1970-1980), the biomass estimate (using a logarithmic transformation; Kenchington, 1981) for each NAFO Division was split into the percentage contribution by each of its strata. From the eleven percentages for each stratum, a median, range and inter-quartile range were calculated (Table 1). Corresponding percentages were calculated for each stratum for each of the spring and fall surveys. If, as hypothesized, redfish make very limited migrations, most spring and fall percentages should fall within the July ranges, and about half should fall within the inter-quartile range, for their stratum.

Table 2 and figures 2 and 3 indicate the deviations from this pattern. It can be seen that deviations do occur, but they have no interpretable pattern. These results could be produced by various forms of migration, but they are consistent with a hypothesis of annual movements on a similar scale to the sizes of strata (approximately 50 km).

Superimposed on these limited annual movements are extensive, slow, unidirectional "drifts". Mayo (1980) found evidence for a gradual movement into deeper water, with increasing age, by <u>S. fasciatus</u> in the Gulf of Maine. Templeman and Squires (1960) suggested slow movements of redfish along the Continental Slope southeastwards from Labrador and westwards in the Laurentian Channel, based on the presence of the dead heads of the parasite <u>Sphyrion lumpi</u> in their flesh. Such heads are found in some fish off Nova Scotia, although live <u>Sphyrion</u> have very rarely been seen on the Scotian Shelf. A similar drift has been suggested from NAFO Division 30 to 3N (Konstantinov and Noskov, 1980) and (by Sebastes jordani) along the coast of California (Lenarz, 1980).

For the Scotian Shelf, a series of length frequencies of redfish were prepared by Clay (1980) and repeated (with annual additions) by Kenchington (1981) and Zwanenburg <u>et al.</u> (1982). Clay (1980) suggested, on the basis of these, that there may be a movement from Division 4Vs to 4Vn (which might continue as the westward movement in the Laurentian Channel noted by Templeman and Squires, 1960). The lack of small redfish in the Fundian Channel (Clay, 1980) suggests either total recruitment failure or, more probably, a drift into this area from elsewhere.

## Larval Distribution

It follows from the limited annual migrations suggested above that larvae should be released in all areas inhabited by adult redfish, and so the distribution of newly-released larvae should approximate to that of the adults. The only suitable larval data are those of the Scotian Shelf Ichthyoplankton Program. Data are presently available for 8 cruises, spread over 20 months and covering every month of the year except October and December. Of the gears used, only Bongo net catches have yet been studied.

For each cruise in which redfish were caught, a chart was prepared showing the catches of all redfish larvae (defined as being less than 14mm in length), and another showing catches of those of length 7mm or less. (For some stations no larvae were measured, resulting in spurious "zero" catches for this size class.) This length is a compromise, being approximately the size at release (Taning, 1961; Bainbridge and Cooper, 1971; Moser <u>et al.</u>, 1977) and yet including sufficient records to give meaningful charts.

No redfish were taken by cruises between November and February. Only one larva was taken by Bongo net in September. The charts of complete catches for the five remaining cruises form figures 4 to 8. The boundary of the surveyed area is shown in each case. Figure 4 shows there to have been few larvae over the Shelf in the March-April period, but it should be noted that the survey did not include Banquereau Bank, and indeed the highest concentrations of larvae were taken at the edge of the surveyed area.

In May (Figure 5) the pattern was quite different with larvae spread all over the eastern half of the Scotian Shelf, and on Georges Bank. June and July showed even wider dispersal, while by August (Figures 7 and 8) the center of concentration had moved to the western half of the shelf.

The charts for small larvae (Figures 9 to 13) show that they are as widespread as the larger ones. (Major differences from the earlier

charts, especially for cruises H050, H036, and VN01, are due to a lack of measurements in more western areas.) Thus, it appears that larval release begins along the Continental Slope in March (perhaps involving only <u>Sebastes mentella</u>), extends across the eastern part of the Shelf in May, <u>spreads west in June and continues into August</u>. Its distribution seems to be as widespread as that of the adults. Because young larvae are so widespread, it is not possible to map larval drift using surveys with the resolution of the SSIP ones.

#### Pre-Recruitment Movements

No data whatsoever are available on the movements of Scotian Shelf redfish in the period before they become fully recruited to the groundfish survey gear. It is thus necessary to speculate on probable movements. In particular, it is important to consider whether any denatent migration (Harden Jones, 1968) occurs, and if so whether it is compensated for by a contranatent migration later in life.

In all cases known to the author, young planktonic larvae of marine fishes drift with the current, but modify their movements somewhat by vertical migration. The same is presumably true of Scotian Shelf redfish.

At a later stage, some fishes show a more developed pattern of behaviour which allows them to exploit favourable water movements and reach, or remain in, desirable areas. North Sea plaice move inshore to the nursery grounds in this way (Cusing, 1975) and herring larvae may hold their position in the Bay of Fundy by such methods (Iles, 1971; Stobo and Iles, 1973). These types of behaviour require relatively constant hydrographic conditions, so that the fish can adapt to them. They also imply fairly localized spawning, so that the drifting larvae reach a hydrographically - appropriate point at the time that their specialized behaviour begins.

There does not appear to be a suitable index by which the variability of water movements in various areas can be compared, from a larval fish's point of view. It would have to compare the strength and frequency of random movements (mostly wind-induced) with the magnitude of cyclical tidal streams and mean residual currents. The physical and chemical properties of the water masses would affect a larva's ability to detect, and hence to respond to, water movements under certain circumstances. Despite this uncertainty, it is clear that tidal estuaries and embayments (with alternating tidal streams, strong velocity gradients and negligible wind-induced flows) make it simple for a plankter to control its position by appropriate vertical migration (as Wood and Hargis (1971) have shown for oyster larvae). The Scotian Shelf, however, lacks these advantages and dramatic changes in water movements sometimes occur (e.g. Trites, 1979).

Redfish larvae are released into these variable flows over wide areas and a long season. It is thus very unlikely that they have evolved highly specific responses to localized currents. It is more likely that they drift with whatever flows they encounter, and respond to favourable or unfavourable features of the environment. When they leave the plankton, they presumably seek desirable temperatures, depths and so on, but there is no reason to suppose that they move to a specific "nursery ground".

Thus, I suggest that redfish larvae undergo a variable denatent migration. If the density of newly-metamorphosed offspring of a single female, summed through the many years of her adult life, could be contoured on a chart, I suggest that it would show a broad, low "hill", centered somewhat down the mean current from the females' position, but extending for considerable distances in all directions.

If that is the pattern of the denatent migration, navigation during a contranatent migration would be very difficult. If the fish used a few, well defined, mating and larval release areas, such navigation might be possible using pheromones or other direct guides. However, the limited adult migration implies that, for redfish, these areas are highly dispersed. If the parental group were involved in a long-term drift migration, releasing larvae at a different point each year, navigation during a contranatent migration becomes almost inconceivable. Therefore, I suggest that such a migration is limited to moving up the mean current sufficiently for the center of the hypothetical "hill" mentionned above to coincide with the parents' position. The offspring of any one group of redfish could, therefore, recruit over a wide area.

The extent of this area is quite unknown. If, as Allendorf and Phelps (1981) have suggested, an interchange of even a very few individuals per generation can prevent genetic divergence (in the absence of selection), then pre-recruitment movements may be sufficient to maintain genetic similarity within redfish species across very large areas of the northwest Atlantic. Sufficient recruitment to affect future catches would be more localized, but if good larval survival in the Gulf of St. Lawrence coincided with a particularly strong outflow through the Cabot Strait, it might well result in a strong year-class on the Scotian Shelf.

If this degree of pre-recruitment movement occurs, young redfish should be found outside the adult range and unable to return. When these die before maturity, they demonstrate only the high mortality that is typical of ichthyoplankton. However, when they survive and form an expatriate (non-breeding) population, they show that mass movements of viable young fish can occur. Zakharov (1962) has suggested that the southwest Greenland redfish were such an expatriate population, sustained by larvae from Iceland, until rising water temperatures (in 1924) allowed them to mature.

## REDFISH MERISTICS AND MORPHOMETRICS

#### Introduction

The ideas developed above should be tested in various ways, including tagging and electrophoretic studies. However, the only data that are available at present are a file of meristic and morphometric characters for Scotian Shelf redfish. These were originally gathered for a more conventional study of "stocks" and so are not ideally suited to present purposes. They are only useful for Sebastes fasciatus.

These data have already been used in a study of the differences between <u>Sebastes fasciatus</u> and <u>S. mentella</u> (Kenchington, in prep.). It was shown that the morphometric data indicate isometric growth and, when the effect of size is removed, approximately normally-distributed residuals. The meristic characters, on the other hand, have severe departures from normality.

## Methods

Most of the fish were collected during routine groundfish surveys by Marine Fish Division. Four were collected from an inshore fisherman's bycatch, in St. Margaret's Bay, N.S. The rest were gathered during other research cruises, including deep trawling on the Continental Slope and an intensive groundfish survey of the Roseway Bank area. The distribution of sets (Figure 14) covered all parts of the Scotian Shelf, but with the greatest density between 62° and 66° west longitude. 876 fish were included in the original data file.

Up to forty morphometric and meristic characters were recorded for each fish. Those which were taken for sufficient individuals to be used here are shown in table 3. Morphometric measurements were taken to the nearest millimetre using dividers and a measuring board. Dorsal and anal fin ray counts exclude the final half element. Vertebral counts were taken from radiographs, and excluded the urostylar half vertebra.

These data included the blackbelly rosefish (<u>Helicolenus</u> <u>dactylopterus</u>) as well as all forms of <u>Sebastes</u> found in the area. <u>Helicolenus</u> were identified on the basis of their dorsal fin spine, anal fin ray, and vertebral counts (Kenchington, 1980) and were eliminated from the file. Sebastes mentella can be distinguished from <u>S. fasciatus</u> by a combination of anal fin ray and vertebral counts in most cases (Ni, 1981a). Fish with 31 vertebrae or 9 or more anal fin rays were therefore identified as <u>S. mentella</u>. These were found in four sets. Fish with 8 anal fin rays and 30 vertebrae could be either species. For the four sets in which <u>S. mentella</u> occured, they were identified as that species (32 fish). In all other cases they were considered to be <u>S. fasciatus</u> (41 fish). After <u>S. mentella</u> had been removed from the data file, 733 fish remained. 586 of these had a complete set of meristic data, while 710 had all the morphometrics.

Because of the effects of size on morphometric characters, and because of the distributional problems with the meristic data, the two groups of characters were separately analysed throughout. The morphometric data were first subjected to a principal components analysis (using BMDP4M, in the Biomedical Computer Programs package). This analysis was based on a covariance matrix of logarithm-transformed data. The first factor calculated by this analysis was taken to represent "size" (Pimentel, 1979), and the remaining factors were considered to summarize the "shape" of the individual. Each transformed morphometric character was then regressed against factor 1, and the residuals calculated. These residuals are alternative, size-independent, measures of shape.

The variation of morphology was then examined by plotting, for every fish, each character (raw meristics, morphometric residuals and the factor scores) against: its position along the Scotian Shelf (from a line drawn along the center of the Laurentian Channel) and across the Shelf (from a line drawn along the Bay of Fundy, perpendicular to the above line), its depth of capture, and its season of capture (with winter coded as 1 and fall as 4). Separate plots were prepared for each sex, as well as ones for sexes combined. Correlation coefficients were calculated for every pair of plots.)

Discriminant analyses (using BMDP7M) were used to check for significant differences between various groups of fish. Analyses were performed between sexes, between fish caught in each of the NAFO Divisions 4Vn, 4Vs, 4W, and 4X, and between fish caught in each of three potential management units. These were the Shelf and Slope groups (a separation first suggested by Martin (1953), and here using the line from Scaterie to Western Bank and thence to Browns Bank, which was suggested by Kohler, 1968) and a Gulf of Maine group, defined as west of a line drawn due south from Cape Sable. Separate analyses were performed with raw meristic data and with morphometric residuals. The use of these residuals removes the effects of fish size, without loosing a direct correspondence to the raw data (as would occur with the factor scores). Furthermore, discriminant analysis requires some correlation between variables (Pimentel, 1979) which is lacking for the orthogonal factors produced by principal components analysis. Apart from the between-sexes analysis, separate analyses were performed for each sex for the morphometric residuals.

Finally, the data were clustered. For clusters of individuals, BMDP2M was used, first with raw meristic data and secondly with factor scores from the second and subsequent factors produced by the principal components analysis. The distance measure used was "sums-of-squares", a form of Euclidean distance.

Clusters of sets were based on an adaptation of a method devised by McGlade (1980), using a matrix of distances in discriminant space. Unfortunately, the available computer could not perform a discriminant analysis between the large number of sets involved. Three separate analyses were therefore prepared for both the meristic and the morphometric data, using the same forms of data as in the earlier discriminant analyses. In each analysis, the least disimilar sets (based on the F-matrix) were combined iteratively, provided that no set was added to a group if it was significantly different (at P < 0.05) from any set already in the group. The positions of these sets were then examined, and non-adjacent sets were removed from each group. This

process yielded 26 sets and groups of sets with morphometric data and 23 with meristics. Further discriminant analyses were then performed, with separate analyses for each sex and for combined sexes with morphometric data. From the values of the canonical variables at each group centroid, the distance between the centoids (in discriminant space) was calculated.

These distances ignore dispersion within the groups, whereas McGlade's (1980) method, using (for each pair of groups) the mean of the distances from the centroid of one to the individual points in the other, takes it into account. The method used here was chosen for its practicality, and should be seen as only a first attempt at the analysis.

The resulting matrices of distances were clustered using BMDP1M. Complete linkage was used to minimize "chaining" in the clusters.

## Results

The principal components analysis produced a first factor that had strong positive loadings by all the characters, and accounted for over 70% of the variance of the data set (Table 4). It can therefore be considered a measure of overall size (Pimentel, 1979). The other factors had weaker loadings, some of which were negative, and thus they represent summaries of the shape of the fish. Plots of the factor scores (Figure 15) suggest a single group with an approximately multivariate-normal distribution of internal variation.

The scatter diagrams relating morphological characters to environmental variables showed little interpretable pattern. Figure 16 shows selected plots. The correlation coefficients are listed in table 5. Although there are many significant (at P < 0.01) correlations, the highest value of r is only 0.319 ( $r^2 = 0.147$ ). Such weak correlations, although statistically significant, may not be biologically meaningful. Correlations with the along-Shelf variable have some consistency between sexes, and suggest that more southwesterly fish are larger, relatively shorter and deeper bodied for their size, with fewer vertebrae. Inspection of the scatter diagrams (Figure 16) shows that the size increase is due solely to the presence of larger fish at the extreme southwest. These fish were caught in the Fundian Channel. The other trends seem to be more continuous. Morphological trends across the Shelf are less consistent, but at least snout length appears to increase slightly offshore. Depth, perhaps surprisingly, shows little relation to morphology. Factor 4, to which it is significantly correlated, has a positive loading by interorbital, and negative ones by snout, schabel and orbit (Table 4). The correlations with season are also weak (showing that there is no great change in the characters of the fish present, and hence adding support to the hypothesis of limited migration) and may be artifacts of sampling different areas in each season. The rate of "growth" implied by the correlation between season and factor 1 (i.e. size) is too high to represent growth in this species.

Of the discriminant analyses between sexes, the one on meristic data found a significant difference only in pectoral rays (Table 6). Since this is not used in discriminating between sets (see below) it could be ignored and sexes can be considered together for analysis of meristic data. For morphometrics, however, there were considerable differences between the sexes (Table 6), showing that separate analysis is necessary.

The discriminant analyses between areas (NAFO Divisions and Shelf/Slope/Gulf of Maine) found a variety of significant differences (Table 7). These differences involve the same data that showed the trends described above, and are the result of dividing the along-Shelf and across-Shelf variables into discrete units and then comparing them. The significant differences do not indicate that the areas represent distinct groups of fish, as is shown by the low percentages "identified" to their own area by the discriminant function (Table 7).

The clusters of individuals are not shown here because of their size (several hundred fish in each). They show no interpretable patterns and appear to indicate a single, internally variable, group. The

discriminant analyses of sets involve more groups than variables, and so are of questionable value. No results are used here, except for the matricies of distances. Figures 17 and 18 present the results of the clustering. Although the clusters appear to be well structured, they group some non-adjacent sets and there is little consistancy between the sexes and between meristic and morphometric data.

#### Summary

Both the principal components analysis and the cluster of individuals suggest that these fish were drawn from a single group. However, the discriminant analyses show that there are significant differences between NAFO Divisions and between Shelf and Continental Slope areas. The scatter plots and accompanying correlation coefficients suggest that these differences are composed of continuous trends, or such small steps that they are concealed by variation within each step. Clusters of sets failed to demonstrate clear units within the group.

Taken together, these results appear to indicate that the redfish of the Scotian Shelf vary phenotypically in a more-or-less continuous (though not constant) way. Any steps in that gradient cannot be dectected with the present data set and methods. Such phenotypic variation is consistent with the genetic relationships suggested on the basis of hypothetical pre-recruitment movements. It does not, of course, prove those relationships.

#### GENERAL DISCUSSION

#### Population Structure

It is now possible to construct a hypothesis of the population units and population structure of Scotian Shelf redfish. Firstly, the population is divided into three genetically-distinct units: the species <u>Sebastes marinus</u>, <u>S. mentella</u>, and <u>S. fasciatus</u>. The first of these is rare, and can be ignored. Each of the other two forms part of a much larger unit, comprising all members of its species over a great part of the northwest Atlantic. Within these large units, there are no genetic barriers, although there are continuous clines in genotype. This situation is maintained by exchange of individuals, primarily as larvae but also by adult drift migrations.

At any point on these genotypic clines, the fish can be divided into separate year-classes (another level in the population structure). The abundance of each, and its genetic, phenotypic and other characters, is determined in part by the water flows during its larval period. Strong southerly flows would carry larvae southwards, introducing a northern form into more southern parts of the cline. In this way, a "patchwork" would result with the fish of one year-class in one locality being quite similar, but relatively distinct from the other year-classes living naerby. The strength of each year-class would also vary locally, depending on the abundance of larvae carried to each place. However, this variation would be superimposed on the year-to-year variations, which are particularly strong in redfish.

Within each year-class, the smallest unit might be the individual fish, or there may be groups of closely-similar individuals which act together and could be considered to be "steps" on the genotypic and phenotypic clines. Such groups would be analagous to Lebedev's (1967) "elementary populations". In their original conception (which was based on many studies of anchovy in the Sea of Azov) these were groups of fish which came together at metamorphosis, and subsequently experienced very similar environments because they were together. This similarity of experience led to a similarity of response and of characteristics, allowing an elementary population to be a recognizable and relatively stable unit throughout the life of the fish. Elementary populations were not, however, thought to be self reproducing: their offspring should intermingle in the plankton. Although his ideas have been almost unrecognized by fisheries biologists outside the USSR, Lebedev (1967) was able to present a great deal of evidence for his theory and to show examples in many species. He suggested that the "stocks" of redfish, which Yanulov (1962a, b) had described from the northwest Atlantic, might actually be elementary populations. However, this was probably an error on Lebedev's part, since Yanulov's "stocks" were large (each occupied one or more NAFO Divisions), and comprised fish of all ages.

Subsequently, Altukhov (1974, 1981) has described much smaller groups of redfish from NAFO Subarea 3, to which he applied the term "elementary population". His analysis was based on trawling data from NAFO Divisions 3KLNOP (Altukhov, 1974). He compared length-frequencies, sex ratios and "features of the interlinking of catches" (by which he may mean geographic proximity) to group the sets into 22 elementary populations. He then demonstrated differences between these populations in a genotypic character: the frequency of the A blood group.

Unfortunately, there are a number of difficulties with Altukhov's (1974) analysis. Firstly, he presented no statistical test of the observed variations in gene frequency. However, an attempt by the present author to recreate Altukhov's data from his published figures and to test them, suggested that at least some of the elementary populations had very significantly different gene frequencies. Secondly, in his original study, Altukhov did not separate <u>Sebastes fasciatus</u> from S. mentella. He rexamined his samples after Barzukov and Zakharov's (1972) study was published, and concluded that <u>S. fasciatus</u> was only found in 6 of the 72 sets (Altukhov, 1974). However, examination of Ni's (1981b, c) data strongly suggests that a majority of the redfish at the depths at which Altukhov fished are S. fasciatus. Thus, the genetic differences might be due to varied mixtures of two species, rather than to intraspecific differences. This requires further study. Finally, Altukhov applied the term "elementary population" to groups containing several year-classes (some varying in length from less than 20 to more than 40 cms (Altukhov, 1974), which represents perhaps 20 years of growth in these fish). Such a group is certainly not an elementary population in Lebedev's (1967) original sense, and it may not be a meaningful population unit. In conclusion, there is no evidence from the Scotian Shelf to suggest that the redfish form any kind of elementary population. or other group within their year-classes, but Altukhov's work may suggest the existence of such groups.

Whatever the smallest units may be, they undertake limited annual migrations, and so can only interbreed with other fish living in their own locality. Some of these individuals or units undertake prolonged, slow drift migrations.

The above hypothesis is in no sense proven. Indeed, in parts it is little more than speculation. However, it is the best available hypothesis at present, and provides some basis for a discussion of management strategies.

#### Fisheries Management

It is clear that the population structure described above does not have a unique population unit that is ideal as an assessment or management unit, in the way that a conventional "stock" is ideal. Instead, it has a hierarchy of units, each of which has advantages and disadvantages as a unit for management purposes. To determine which is best, one must first examine the needs of fisheries management and the fishing industry.

Firstly, it should be pointed out that the arrangement of assessment and management units must be linked to the population structure. This is an intuitive conclusion, but has been supported by theoretical studies (Paulik <u>et al.</u>, 1967; Fukuda, 1973) and by practical experience (e.g. whaling management and the "blue whale unit"; Gulland, 1974). Failure to manage distinct population units separately leads either to the setting of lower Total Allowable Catches than might have been, or to the overexploitation of some population units (Paulik <u>et al.</u>, 1967; Fukuda, 1973). Fisheries management in the northwest Atlantic is not presently concerned with the genotype or the fish caught. This is a legitimate concern in freshwater fisheries, where the loss of small, genetically-specialized population units results in a reduction of genetic diversity. In the sea, however, the total loss of a genotype is unusual. Given the size of the genetic units suggested for redfish, this problem can be ignored.

Futhermore, management is not generally concerned with the abundance of recruits. Stock-recruit relationships are only invoked when adult abundance is seriously depressed: a situation that has not yet occured for northwest Atlantic redfish.

Thus, the concern of fisheries management lies in maximizing yields from the recruited fish that are available. Assessment methods usually involve a combination of research vessel and commercial data and the use of sequential population and yield-per-recruit analyses. It is, therefore, important that whatever assessment unit is chosen, it should fulfill the assumptions of these analyses: assumptions that have rarely been clearly stated. If the assumptions cannot be fulfilled, within a reasonable degree of approximation, a different approach to assessment must be devised.

There is also an over-riding need for the assessment unts to permit practical assessments. Theoretical perfection is valuless if it cannot be applied.

The industry's needs are harder to determine. The Scotian Shelf redfish fishery is relatively simple. It is almost exclusively carried out by large offshore trawlers, most of which work out of Nova Scotian ports. There is little bycatch of redfish in other fisheries, or of other species in the redfish fishery. Thus, many of the technical and political problems seen in other fisheries do not arise. However, at least part (and it could be a large part) of the fishery is at such depths that both <u>Sebastes mentella</u> and <u>S. fasciatus</u> are caught (K. Zwanenburg, pers. comm.). The fishermen do not, and probably could not, distinguish these species. Joint management is, therefore, essential.

Thus, neither the large genetic units nor the extent of significant pre-recruitment movements are necessarily suitable assessment or management units for Scotian Shelf redfish. They are much larger than the area which a single fish or elementary population occupies, and so removal of fish from one part of such an area cannot be compensated by increased production by fish in other parts. Use of these areas as assessment units would cause the same difficulties as attempting to jointly manage discrete population units (such as conventional "stocks").

The only other levels in the population structure are year-classes (which seem totally impractical as assessment units), elementary populations (if any) and the individual fish. Neither of the latter is large enough for practical assessment, let along management. It is, therefore, necessary to define arbitrary areas as assessment units. The larger these are, the simpler the assessment process will be but the greater will be the deviations from the assumptions of the assessment models. The two species should, of course, be assessed separately.

Within the chosen assessment unit, the hypothesized population structure would cause severe difficulties. The adult drift migrations would carry significant parts of the population from one unit to another. Ulltang (1978) investigated the effects of a simple movement on virtual population analyses, and showed it to casuse considerable errors. The complex of movements suggested here might have even more severe consequences. Local variations in year-class strength would produce errors in age/length keys, and so in tables of numbers-at-age. The pronounced variations in year-class strengths between years may tend to inflate estimates of allowable catch (Sinclair et al., 1981).

Recent attempts to assess Scotian Shelf redfish (Clay, 1979, 1980; Kenchington, 1981; Zwanenburg, et al., 1982) have shown that there are no data on which to base a confident Total Allowable Catch, so any suggestion of subdividing the present management unit may be premature. 1. Determine, by research vessel survey, where redfish of commercial size and of each species occur.

following strategy:

- Determine, from log books and observer records, where the fishery occurs, and which species are caught.
- 3. Hence, determine which concentrations of redfish are being most heavily exploited.
- 4. Assess these concentrations separately, using whatever data and analyses are available, and making due allowance for drift migrations of adults (into or out of these assessment units) and for the effects of the "patchwork" of elementary populations or individuals on the data (especially on estimates of numbers at age and catch per unit effort).
- Sum the allowable catches, and increase this sum by the proportion of the total catch that is taken outside the assessed areas.
- 6. Apply the resulting Total Allowable Catch to the entire management unit.
- 7. Continue to monitor the distribution of fish and fishery to ensure that removals from each area remain within the surplus production of the local population.

Such a strategy could be applied to much wider areas than the Scotian Shelf, but fishing effort would tend to concentrate on grounds near the fishing ports (to save fuel costs). If the Total Allowable Catch were reduced to protect these areas, production would be wasted on more distant grounds. Thus, management units should remain reasonably small so as to spread the fishing effort. Either the entire Scotian Shelf or each of its separate NAFO Divisions might be suitable management units.

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	MEDIAN	JULY	DANOE	SPR	ING		FALL		
STRATUM	MEDIAN	RANGE	RANGE	1979	1980	1978	1979	1980	
4Vn 40 41 42	99.9 0.1 0	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	89.7-100.0 0 - 10.1 0 - 0.2	NO DATA NO DATA NO DATA	NO DATA NO DATA NO DATA	NO DATA NO DATA NO DATA	94.5 5.5 0	78.1 21.9 0	
4Vs 43 44 45 46 47 48 49 50 51 52	0 16.6 6.7 65.5 0 0 0.0 0 0.0 0 0.4 1.0	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	0 4.1 6.5 42.3 NO DATA 0 NO DATA 0 NO DATA 47.1	NO DATA 0.6 NO DATA 90.0 1.0 0 0.1 1.7 0 5.7	0 9.0 5.6 71.3 0 1.5 0.8 0.8 11.2	0.0 0.8 12.4 81.8 0 2.4 1.5 0 0 0.6	1.7 17.9 10.9 66.4 0 0 0 0 1.3 1.9	
4W 53 54 55 56 57 58 59 60 61 62 63 64 65 66	2.0 0 0.9 0 18.0 26.2 7.9 5.7 0 0 0 0.3	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	$\begin{array}{c} 2.4\\ 0\\ 0\\ 0\\ 0\\ 50.3\\ 5.4\\ 26.6\\ 0\\ 0\\ 5.2\\ 2.1 \end{array}$	0.3 0 0 NO DATA NO DATA 2.2 0 96.5 0 0 0 0 0 1.0	3.3 0 0 0 0 0 0 90.1 0 0 0 0 0 0 0 0 0 0 0	66.6 0 0 13.0 0 15.2 0 0 0 0 0 0 0 0 5.2	0 0 0 0.5 0 99.3 0 0 0 0	
4X 70 71 72 73 74 75 76 77 78 80 81 82 83 84 85 90 91 92 93 94 95	$12.4 \\ 0.6 \\ 0 \\ 0 \\ 0 \\ 0 \\ 3.6 \\ 0 \\ 0.2 \\ 0 \\ 0.5 \\ 0.3 \\ 10.6 \\ 23.1 \\ 0.5 \\ 0.1 \\ 1.4 \\ 0.5 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ $	2.9-23.6 0.4-5.5 0-0 0-0 0-0 0-6.3 0-6.3 0-0 0.1-1.1 0-0 0-0.8 0-1.4 2.9-17.2 19.1-31.9 0-1.5 0-0.3 1.2-2.7 0.2-2.0 0-0 0-0 0-0 0-0 0-0 0-0 0-0 0	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	NO DATA NO DATA	4.8 0 6.9 0 0.3 1.9 0 24.7 0 0 0 8.3 36.1 0 0 8.5 8.4 NO DATA NO DATA	0 0 NO DATA NO DATA NO DATA 0 4.0 3.4 0 0 4.9 11.8 49.4 0 2.6 16.8 7.2 0 0 0	2.4 0.8 0 0 1.3 0 4.0 0 8.6 5.9 62.2 13.2 NO DATA 1.5 0 NO DATA NO DATA NO DATA	2.6 0 0.6 0.1 22.7 0 1.1 0 0 16.0 3.7 49.2 0 0 2.2 1.8 NO DAT/ NO DAT/	

Table 1. Percentage contributions of each stratum to Division biomass estimates.

0.0 = value greater than 0 but less than 0.5

Summary of seasonal deviations in contributions of each stratum.

		SPRING			F	ALL	
STRATUM	1979	1980	OVERALL	1978	1979	1980	OVERALL
4Vn 40 41 42	NO DATA No data No data	NO DATA No data No data	NO DATA No data No data	NO DATA NO DATA NO DATA	- 		• •
$\frac{4Vs}{43}$	•	NO DATA				++	• • • •
45 46	• -	NO DATA +	•	•	+ +	+	+ +
47 48 49	NU DATA	++ • •	•	•	++ +		• + +
50 51 52	NO DATA +	+ •	-?	+		+	•
4W 53 54				•	++		
55 56 57	•	NO DATA	•		• • • •		•
58 59 60 61	• • • • • • • • • • • • • • • • • • •	NU DATA -  ++	• • •			-	-
62 63 64	+	•	?	++	•	++	+?
66 4 Y	• • • • • • • •			++	<b>+</b> +	- 2010 	••••••••••••••••••••••••••••••••••••••
70 71 72 73 74	NO DATA NO DATA NO DATA NO DATA NO DATA	• • •	-? +?	NO DATA NO DATA NO DATA			
75 76 77 78	NO DATA NO DATA NO DATA NO DATA	++ • •	• • • • • • • • • • • • • • • • • • •	NO DATA ++ +	•	++ + •	+ • • • •
80 81 82 83	NO DATA NO DATA NO DATA NO DATA		•	• • • • •	• +	• ++	
84 85 90 91	NU DATA NO DATA NO DATA NO DATA	+ • •	+? • • +?	+ + +	+ ++ NO DATA	• • •	••••••••••••••••••••••••••••••••••••••
92 93 94 95	NO DATA NO DATA NO DATA NO DATA	+ NO DATA NO DATA NO DATA	+? NO DATA NO DATA NO DATA	, 1997 <b>+</b> 1997 - Article Angel 1997 - Article Angel 1997 - Article Angel	NO DATA NO DATA NO DATA NO DATA	NO DATA NO DATA NO DATA	

# Symbols

Within July interquartile range; no overall charge In upper quartile of July range; overall increase In lower quartile of July range; overall decrease Above July range Below July range + 

++

Two or more negative or positive signs are taken as indicating an overall change. While only one year's data are available, a single sign is considered sufficient.

Table 3. Characters used in the Analysis.

	MO	RPHOMETRIC	<u>.</u>	
Name			Definition	
length snout-anal body depth		60 (2) (2) (2) (2) (2) (2) (2) (2) (2) (2)	standard length snout to anal fin origin depth from origin of	
peduncle depth			dorsal fin to origin of ventral fin minimum depth of caudal	
head snout		-	snout to tip of operculum	
schnabel orbit		-	tip of schnabel to top of teeth of lower jaw	
inteorbital				
		MERISTICS		
Name			Definition	
dorsal rays anal rays		- 	dorsal fin soft-ray count anal fin soft-ray count	
vertebrae lower rakers	   	60 97 68	vetebral count count of gill rakers on lower limb of first arch on left side	
upper rakers			likewise for upper arch	

Table 4.

Factor Loadings for Principal Components Analysis of Morphometric Data.

and the second	1				
VARIABLE	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
length	0.266	-0.009	-0.014	0.006	-0.008
snout-anal	0.264	-0.015	-0.010	0.005	-0.009
body depth	0.287	-0.015	-0.019	0.003	-0.019
peduncle depth	0.269	-0.017	0.005	-0.005	-0.041
head	0.269	-0.012	-0.020	-0.004	-0.002
snout	0.254	-0.042	0.069	-0.032	0.021
schnabel	0.373	0.084	0.016	-0.024	0.002
orbit	0.236	-0.014	-0.053	-0.025	0.042
interorbital	0.272	0.004	0.017	0.080	0.021
				water and the state of the stat	
Variance Explained	0.701	0.010	0.009	0.009	0.005

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Table 5.

Correlations between morphological Characters and Environmental Variables.

Values tabulated are r. n is 710 for morphometrics of combined sexes and <sup>⇒</sup> 665 for meristics. For males only these figures are 362 and <sup>⇒</sup> 342. For females 303 and <sup>⇒</sup> 292.

Correlations that are significant at P < 0.01 are marked: \*.

# A: SEXES COMBINED

	Along Shelf	Across Shelf	Depth	Season
Meristic Data	and a second	and a second	amanahamanan	Contraction (Contraction)
dorsal rave	-0.011	0.060	0 102	0.040
anal nave	0.062	-0.009	-0.103	-0.040
anal lays	=0.002	-0.000	0.043	-0.003
pectoral reays	-0.000	-0.09/	0.0/2	-0.029
vertebrae	-0.1/3*	-0.029	-0.109	-0.050
lower rakers	0.043	-0.148*	-0.155*	-0.084
upper rakers	0.113*	-0.170*	-0.083	-0.108
Factors				
1	0.178*	-0.264*	-0.032	0.190*
2	-0.029	-0.057	-0.073	-0.012
3	-0.166*	-0.175*	-0.016	0.123*
4	-0.091	-0.055	-0.153*	-0.026
Morphometric Residuals				
length	-0.173*	0.014	-0.044	0.047
snout-anal	-0.125*	0.020	-0.003	-0.006
body denth	0.188*	_0 11/*	0.000	-0.000
neduncle denth	0.137*	-0.114	-0.043	0 171*
head	0.130*	-0.001	0.043	-0.1/1"
cnout	0.138	-0.115	0.007	-0.049
schabol	-0.100	0.103	-0.110	0.040
Schhabel	-0.033	-0.00/	-0.023	0.020
	0.14/*	-0.074	0.0/3	-0.050
Interordital	0.113*	-0.016	-0.131*	0.010
B: MALES ONLY	Along Shelf	Across Shelf	Denth	Season
Meristic Data	Arong Sherr	ACTOSS SHELL	Depen	<u></u>
dorsal rays	0.011	-0.056	-0.153*	-0.071
anal rays	_0 079	0.000	0.052	-0 044
anai rays	-0.075	0.125	0.052	0.044
pectoral rays	-0.070	-0.052	-0 166*	-0.014
leve	=0.173"	-0.052	0.110	-0.014
upper rakers	0.000	-0.131*	-0.034	-0.140*
Factors				
and a manufactory of the second se				
<b>1</b>	0.185*	-0.229*	-0.062	0.142*
2	-0.003	-0.077	-0.039	0.004
3	-0.160*	0.116	-0.007	0.070
4	-0.122*	-0.072	-0.169*	-0.009
Morphometric Residuals				n on a statistica National and an an National and a
length	-0.225*	0.107	-0.047	0.034
snout-anal	-0.196*	0.136*	-0.022	-0.024
body depth	0.202*	-0.010	0.062	0.019
peduncle depth	0.151*	0.006	-0.065	-0.219*
head	0.093	-0.091	0.056	-0.032
snout	-0-098	0.144*	0.091	0.103
schnabel	-0.001	-0.034	0.006	0.021
orhit	0 163*	-0-091	0.078	-0.004
interorbital	-0.130*	-0.079	-0.152	0.028
THE CLOSE CONTRACTOR	~			그는 아이지 하는 것 같아.

Table 5. (Continued)				
C: FEMALES ONLY				n sa An an
Meristic Data	Along Shelf	Across Shelf	Depth	Season
dorsal rays	-0.057	0.031	-0.011	-0.017
anal rays	-0.042	-0.001	0.058	0.045
pectoral rays	-0.060	0.104	0.045	0.018
vertebrae	-0.163*	0.014	-0.060	-0.145
lower rakers	0.074	-0.063*	-0.173*	-0.144
upper rakers	0.104	-0.162*	-0.081	-0.070
Factors				
1	0.265*	-0.134	0.223*	0.319*
2	-0.076	-0.026	-0.002	-0.019
3	-0.189*	0.164*	-0.009	0.132
4	-0.071	-0.084	-0.225*	-0.066
Morphometric Residuals				
length	-0.167*	0.056	-0.047	0.115
snout-anal	-0.052	-0.065	-0.046	0.021
body depth	0.241*	-0.174*	-0.092	-0.046
peduncle depth	0.149*	-0.040	-0.039	-0.190*
head	0.202*	-0.106	0.153*	-0.021
snout	-0.115	0.187*	0.085	0.167*
schnabel	-0.090	-0.029	0.056	0.026
orbit	0.142	-0.025	0.121	-0.066
interorbital	-0.116	-0.021	-0.189*	-0.031

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Table 6: Discriminant analyses between sexes.

Meristics Before Analysis: Character F to Enter Degrees of Freedom dorsal rays 1.097 1,558 0.305 anal rays pectoral rays 5.698 0.706 vertebrae lower rakers 0.860 upper rakers 0.165 Pectoral rays was the only character entered. = 0.9898734, Approx. F = 5.698, d.f. = 1,557 Between Sexes: Wilks' Morphometrics Before Analysis: Character F to Enter Degrees of Freedom (residuals) Tength 28.165 1,663 46.488 46.272 snout-anal body depth peduncle depth 7.258 head 1.774 snout 0.672 schnabel 15.981 orbit 38.939 interorbital 0.834 Summary of Analysis: Character F to Enter Entered snout-anal 46.488 body depth 39.056 orbit 33.846 head 14.594 peduncle depth 4.314 interorbital 2.183

Between Sexes: Wilk's = 0.8132344, Approx. F = 25.186, d.f. = 6,663

## \_\_\_\_\_\_

Table 7.

Discriminant analyses between areas.

BETWEEN DIVISIONS, M	ERISTICS							,			
SUMMARY OF ANALYSIS		F -	MATRIX					CLASSIF	ICATION	MATRIX	
Character Entered vertebrae upper rakers dorsal rays pectoral rays lower rakers anal rays	F to Enter 12.507 7.910 5.044 4.505 4.208 2.650	Vs W X	Vn 3.39 4.83 4.47 8	<u>Vs</u> 7.19 3.61 5.	<u> </u> d.f. 84	= 6,57	77	Actual Group Vn Vs W X	Assigne <u>Vn</u> <u>Vs</u> <u>4</u> 0 10 21 11 29 35 47	d Group <u>W X</u> 0 1 12 14 66 41 98 197	Percent <u>Correct</u> 80.0 36.8 44.9 52.3
BEIWEEN DIVISIONS, MO	RPHUME IRICS,	MALE						CLASSIE		ANTDIV	
SUMMARY OF ANALYSIS		F - 1	MATRIX					Actual	Assigned	i Group	Percent
Character Entered F length orbit peduncle depth body depth snout-anal head	to Enter 12.475 4.597 4.598 3.476 3.222 2.964	Vs W X	Vn 3.40 2.69 9 2.65 11	<u>Vs W</u> .49 .09 1.8	_ d.f. 5	= 6,35	3	Group Vn Vs W X	Vn Vs 2 0 1 29 7 15 12 49	$ \frac{W}{0} = \frac{X}{0} $ 7 5 31 26 66 112	<u>Correct</u> 100.0 69.0 39.2 46.9
BETWEEN DIVISIONS, MO	ORPHOMETRICS	, FEMALE							TCATION		
SUMMARY OF ANALYSIS		F -	MATRIX						Assigne	MAIRIX d. Group	Percent
Character Entered I length head body depth peduncle depth snout-anal orbit	F to Enter 15.168 9.331 6.314 4.580 2.337 2.343	Vs W X	Vn 2.74 3.35 10 3.59 10	<u>Vs</u> <u>k</u> ).03 ).076.	43	= 6,29	)4	Group Vn Vs W X	$\frac{Vn}{2} \frac{Vs}{0} \\ 2 \\ 2 \\ 5 \\ 11 \\ 2 \\ 42$	$\begin{array}{c} W \\ \hline W \\ \hline 0 \\ \hline$	Correct 100.0 68.4 44.9 53.1
BETWEEN POTENTIAL MAN	AGEMENT UNI	TS, MERIS	TICS								
SUMMARY OF ANALYSIS		F – MATR	IX				CLASSIF	ICATION	MATRIX		
<u>Character Entered</u> pectoral rays upper rakers	to Enter 6.9436 6.2363	Gulf of Maine Shelf	<u>Slope</u> 5.34 10.69	Gulf of <u>Maine</u> 2.38	d.f. =	2,582	Actual <u>Group</u> Slope Gulf of Maine Shelf	As <u>Slope</u> 113 40 174	signed G Gulf of <u>Maine</u> 28 19 62	roup <u>Shelf</u> <u>35</u> 21 94	Percent Correct 64.2 23.8 28.5
BETWEEN POTENTIAL MAN	NAGEMENT UNI	IS, MURPH	UMETRICS	, MALE			CLASSIE	ICATION	MATRIX		
SUMMARY OF ANALYSIS Character Entered body depth snout-anal snout length head schnabel	F to Enter 8.978 7.860 5.250 7.281 5.563 2.427	F - MATR Gulf of Maine Shelf	IX <u>Slope</u> 8.98 4.33	Gulf of <u>Maine</u> 7.40	_d.f. =	6,354	Actual <u>Group</u> Slope Gulf of Maine Shelf	As <u>Slope</u> 58 7 7 72	signed G Gulf of <u>Maine</u> 18 36 50	roup Shelf 31 9 81	Percent <u>Correct</u> 54.2 69.2 39.9
BETWEEN POTENTIAL MAN	AGEMENT UNI	IS, MORPH	OMETRICS	, FEMALE							
SUMMARY OF ANALYSIS		F – MATR	IX				CLASSIF	ICATION	MATRIX		
Character Entered F length head snout schnabel body depth snout-anal	to Enter 6.900 10.631 5.971 5.589 2.901 3.346	Gulf of Maine Shelf	<u>Slope</u> 7.62 7.29	Gulf of <u>Maine</u> 3.82	d.f. =	6,295	Actual <u>Group</u> Slope Gulf of Maine Shelf	As <u>Slope</u> 55 8 51	signed Gu Gulf of <u>Maine</u> 15 28 53	roup <u>Shelf</u> 14 12 67	Percent <u>Correct</u> 65.5 54.2 38.6



Figure 1. Distribution of adult redfish, based on charts by Scott (1976, 1981). Cross-hatching indicates major concentrations.













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![](_page_28_Figure_0.jpeg)

![](_page_28_Figure_1.jpeg)

![](_page_29_Figure_0.jpeg)

![](_page_29_Figure_1.jpeg)

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b. Factor 3 against Factor 1.

ī

3.

![](_page_30_Figure_0.jpeg)

![](_page_31_Figure_0.jpeg)

Figure 16. Scatterplots of morphological characters against environmental variables. (Numbers indicate the number of overlapping points. Letters indicate numbers greater than 9; i.e. A=10, B=11, etc. \* indicates 20 or more overlapping points.)

a. Factor 1 against along-shelf.

![](_page_32_Figure_0.jpeg)

b.

Length residual against along-shelf.

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![](_page_33_Figure_0.jpeg)

![](_page_33_Figure_1.jpeg)

c. Depth residual against along-shelf.

![](_page_34_Figure_0.jpeg)

![](_page_34_Figure_1.jpeg)

d. Vertebrae against along-shelf.

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![](_page_35_Figure_0.jpeg)

Figure 16.

16. (Continued)

e. Snout residual against across-shelf.

![](_page_36_Figure_0.jpeg)

![](_page_36_Figure_1.jpeg)

f. Factor 4 against water depth.

![](_page_37_Figure_0.jpeg)

![](_page_37_Figure_1.jpeg)

g. Factor 1 against season (Winter coded 1, Spring 2, Summer 3, and Fall 4).

![](_page_38_Figure_0.jpeg)

![](_page_39_Figure_0.jpeg)

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![](_page_40_Figure_0.jpeg)

b. Sets and groups of sets used in morphometrics clusters.

![](_page_41_Figure_0.jpeg)

d. Groups clustered at a distance of 1.5 using morphometrics, sexes combined.

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![](_page_42_Figure_0.jpeg)

f. Groups clustered at a distance of  $1 \mid .5$  using morphometrics, females only.

![](_page_43_Picture_0.jpeg)