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Indices of Fish Distribution as Indicators of Population Status

Indices de la distribution du poisson comme indicateurs de l'état des populations

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Abstract

We examined measures of concentration, prevalence and local density for seven fishes commonly caught during the annual summer groundfish trawl survey conducted by the Department of Fisheries and Oceans. We also examined the relationship of these distributional indices to estimates of overall species abundance. Concentration was defined as the proportion of the total survey area occupied by the top nth percent of the total annual population estimate. Prevalence was defined as the proportion of the total number of standardized trawl hauls (sets) completed in year i containing > 0 individuals of the species of interest and indicates how widely the species is distributed in the survey area without reference to density. Local density or CPUE where present is the average number (or weight) of the species of interest only in those sets where at least one individual of the species of interest was caught. This measure gives an indication of the average density of the species in those areas where it actually occurs. We conclude that these measures are difficult to interpret individually but in concert provide indicators of various attributes of overall species abundance. They should not be interpreted individually. All should be interpreted over time and with reference to longer-term data and should be interpreted with reference to a map of overall species abundance and in the area of interest.

Résumé

Nous avons examiné des mesures de la concentration, de la prévalence et de la densité locale de sept poissons communément capturés durant le relevé annuel estival du poisson de fond au chalut effectué par le ministère des Pêches et des Océans. Nous avons aussi examiné la relation entre les indices de la distribution et les estimations de l'abondance globale des espèces. La concentration est définie comme la proportion de la zone de relevé occupée par le nième pourcentage le plus élevé de l'estimation annuelle totale de la population. La prévalence, définie comme la proportion du nombre total de traits de chalut normalisés faits dans l'année contenant > 0 individus de l'espèce en cause, indique la distribution de l'espèce dans la zone de relevé sans référence à la densité. La densité locale ou la PUE, lorsque disponible, est le nombre moyen (ou le poids moyen) d'individus de l'espèce en cause présents seulement dans les traits où au moins un individu de cette espèce a été capturé. Cette mesure est un indicateur de la densité moyenne de l'espèce aux endroits où elle est actuellement retrouvée. Nous concluons que ces mesures sont difficiles à interpréter isolément mais que, considérées ensemble, elles peuvent servir d'indicateurs des divers caractères qualitatifs de l'abondance globale d'une espèce. Elles ne devraient cependant pas être interprétées isolément, mais plutôt sur une période de temps, ainsi que par rapport à des données à plus long terme et à une carte de l'abondance globale de l'espèce dans la région d'intérêt.

Introduction

Area occupied and abundance are positively correlated for a number of demersal fish populations (Winters and Wheeler 1985; Creco and Overholtz 1990; Rose and Leggett 1991; Swain and Wade 1993, 1994; Marshall and Frank 1994). In general these studies show that changes in area occupied, over a range of population abundance levels, are the result of an interplay between fish density and geographic area occupied, ostensibly mediated through such density dependent processes as prey density and availability, and habitat preferences. These observations are consistent with the basin model proposed by MacCall (1990). Swain and Wade (1994) show that these processes may also be age or size dependent. These authors point out that no single statistic or index will provide a satisfactory view of the spatial response of a demersal fish population to changes in population abundance.

We examine results of a number of indicators. This is by no means an exhaustive list and the intent should be to examine other indicators to obtain the most complete picture possible. Other indicators which might be examine include the GINI index (Myers and Cadigan 1995) which essentially measures the departure of the species distribution from an even distribution (i.e. a linear 1:1 CDF of cumulative proportion of area vs. cumulative proportion of numbers or biomass). The advantage of this measure is that it measures against a theoretical distribution, however it has shortcomings similar to the present indicators in that it must be judged against historical patterns to be interpretable and meaningful in terms of information on stock status.

Our present interest was to define a number of indices, which together would measure a characteristic of a fish population. Indices of spatial distribution reflect both abundance and the state of the ecosystem. Distribution will also have impacts on catchability and therefor the estimation of abundance of the species by trawl or longline surveys. Distribution will also have an impact on the fishing mortality where aggregation of remnant populations can result in greater availability of the population to fishing efforts. Indices of spatial distribution provide insight into the nature of the distribution and abundance of the species in question. The previous use of population estimates based on areal expansion of trawl survey results to provide a single estimate gave little or no information on the manner in which the species is distributed within its traditional area of distribution nor how the current patterns of distribution and abundance compare to historical patterns or to patterns of exploitation or physical oceanographic parameters.

We present the relatively detailed descriptions and methods of calculation for a number of indices related to the spatial distribution of fish populations. It is our intention that these definitions be sufficiently detailed to allow for their consistent estimation for a variety of fish populations. This would then allow them to be used as inputs to multi-attribute analyses of fish population status known as the traffic light approach (for a detailed description of this approach see Halliday et al, 2001). For each indicator we also give some comment on 'boundary points' these are intended to initial estimates of indicator values which that may represent either target values (i.e. desirable values of the indicator) or boundaries (limits or undesirable values) for the indicators. We also discuss a number of attributes for each indicator including measurability, interpretability, sensitivity, and weight. Measurability is the degree to which the indicator is estimable and the statistical properties of the indicator (if known). Interpretability refers to how well indicator reflects the attribute of the population status (in this case spatial distribution) for which it is estimated. Sensitivity refers to the response of the indicator to changes in the attribute of the population (time lags, etc), and the degree of natural variability in the indicator.

Description

We examine a number of measures that capture aspects of demersal fish population distribution and abundance. These are

1) Proportion of total survey area occupied by the top nth percent of the total population. We interpret this as an index of population **concentration**. Swain and Sinclair (1994) indicated that for cod this index was positively correlated with changes in overall population abundance. They showed that for n = 95 the area occupied was highly correlated with population abundance while for n = 50 the correlation was low. They also indicated that the index was more highly correlated for older than for younger fish. We allow for the examination of any percentile but present results only for n = 75.

2) The proportion of non-zero sets is an index of **prevalence**. This is defined as the proportion of the total number of standardized survey sets completed in year i containing > 0 of the species of interest. This provides an indication of how widely the species is distributed within the survey area without reference to density.

3) The average number per non-zero survey tow or '**cpue where present**. This is indicative of the average **local density** of the species of interest within the survey area. Unlike the stratified mean catch per standard survey tow this measure does not incorporate 0 sets but only estimates density where the species of interest occur in that year.

4) The stratified mean catch per standard survey tow. This is a traditional measure derived from stratified surveys. A recent description can be found in Smith (1996).

Estimation

1) The proportion of the total survey area occupied by the top nth percent of the population was estimated as follows

   i) Survey area is first divided into equal sized square cells. The illustrative example below uses 10 minute squares
   ii) Estimate average catch per standard survey set within each grid cell.
   iii) Rank average catch per grid cell in descending order
   iv) Calculate the cumulative total catch per tow and tally the total number of grid cells with each total

v) Count the number of cells needed to reach the threshold (in this case 75% of the total catch for that year) and express it as a proportion of the total number of survey cells occupied in that year. *Note one can also express this as a proportion of the total number of grid cells occupied in all years of the survey to estimate the current relative to the 'historical' distributional pattern. **Note one can also express this as a proportion of the number of non-zero survey sets occupied in that year or historically. This provides information on how the population is distributed within the boundaries of its known distribution rather than within the boundaries of the surveyed area.

2) The proportion of non-zero sets is the number of sets that catches species i relative to the total number sets in that time period (year).

3) The average number per non-zero set is the average numbers of species I estimated only from those sets in which species i occurred.

4) Estimation of the stratified mean catch per standard survey tow has been previously described (see for example Smith 1996).

Boundary Point(s)

Boundary points for indices of distribution are not well established. The boundary points established for other indicators are not appropriate in this case. The value of the indicators of spatial distribution comes from comparing their values over time and from disaggregating the prevalence and density where present components of abundance.

Concentration

For the proportion of total survey area occupied by the top nth percent of the population, the historical proportion of the survey area occupied might provide a basis for setting boundaries between acceptable and non-acceptable levels of prevalence, although there would still be significant room for debate. It has been shown that populations of some species of groundfish retreat to predictable areas at low abundance. For these populations it may be possible to define minimum areas of distribution. It will be of utmost importance to examine this measure in relation to the distribution of physical oceanographic parameters, fishing effort, and other anthropogenic factors to investigate potential causes for changes in area occupied.

Prevalence

For the proportion of non-zero sets, which is essentially a measure of prevalence of the species within the survey area, the historical distribution is an effective comparator. Establishing boundary conditions for prevalence is likely to be somewhat arbitrary and will likely be couched in more general terms such as 'more or less prevalent' than in some previous time period. Again it will be important and informative to examine this measure in relation to the distribution of physical oceanographic parameters, fishing effort, and other anthropogenic factors to investigate potential causes for changes in prevalence.

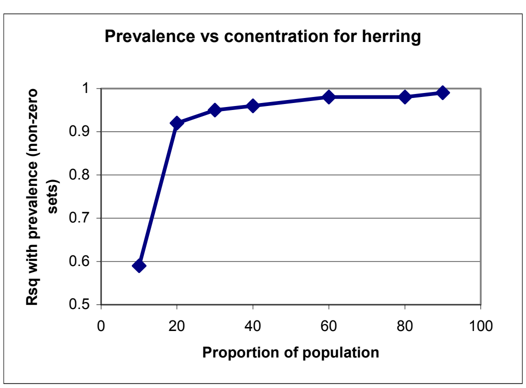
Density where present

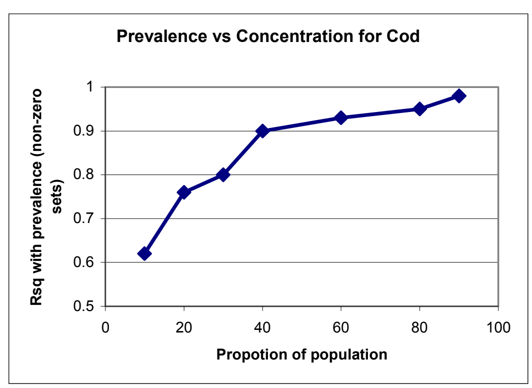
Boundaries for the average number per non-zero set, which defines the average local density of the species within the survey area, will be difficult to establish. This measure gives an indication of the local density of the species of interest. Essentially it tells us how tightly packed the individuals are in areas where they occur at all. Changes in cpue where present will be the result of a complex interaction of population abundance, habitat availability and prey density. High local densities could be the result of dense aggregations of prey items or of a lack of available habitat. As for the other measures it should not be examined in isolation but rather as one of a suite of indicators relative to the distribution of other physical and biological parameters.

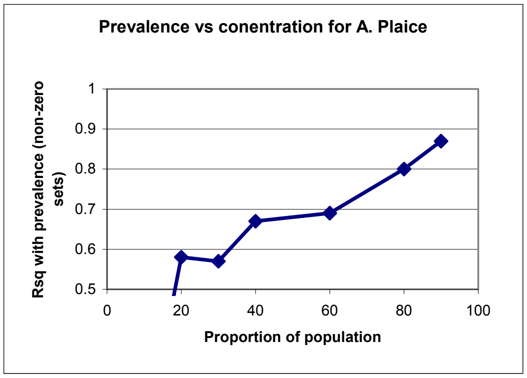
Attributes

Measurability (our confidence in estimate of the indicator)

- All of the indices of spatial distribution are relatively easy to measure once a trawl survey or longline survey is in place.
- Statistical properties have not been explored.
- Estimates for concentration (area containing n% of the population) and cpue where present are based on ln transformed values. Proportion of non-zero sets is expressed as the untransformed proportion.
- The proportion of non-zero sets and the proportion of area with n percent of the population are highly correlated for herring and cod at n's > 40%, however for plaice the relationship between the attributes is different. It is likely that the relationship between prevalence and concentration will vary from species to species because they are the result of interacting processes that differ from species to species. The inherent patch size for the species in question will likely be a significant determinant of this relationship.







Interpretability

These indicators of spatial distribution are difficult to interpret individually and are most informative when examined in concert as indicators of various attributes of abundance. They are also difficult to interpret save as time series of observations. An individual estimate of prevalence or cpue can give some indication of the relative abundance of the species relative to others or how common one species is common to another but gives no information about the dynamics of either prevalence or abundance.

1) *Concentration* (Proportion of total stock area occupied by the top nth percent of the population)

- Gives an indication of the concentration of the species within its traditional area of distribution.
- Should not be interpreted in isolation as an indicator of stock size but rather in conjunction with prevalence and cpue where present (local density) which together give an indication of the overall distributional characteristics of the species.
- Should be interpreted in conjunction with a map of distribution (cpue).
- Should be interpreted in light of information on distribution of human activities (including fishing) and physical environmental conditions (e.g. T).
- Decreasing stock size (overall population numbers) could be the result of a local extirpation of a portion of the population. This would be reflected by a decrease in the area containing a constant proportion of the population. Decreasing stock size could also be the result of overall erosion of population numbers throughout the stock area. This would result in an increase in the area containing a constant proportion of the population. The same arguments hold for increases in stock size. Investigation of where the decreases occurred and whether or not these were associated with human activities or changes in environmental conditions will provide significant insight into population status.
- Establishing boundary conditions for this indicator will likely be by the examination of the historical patterns of concentration for the species in question. The relationship between estimated population size and concentration (if present) might be used to establish combined limits of population size and areas occupied for some pre-defined

portion of the population. Changes in concentration should prompt investigations into cause.

2) *Prevalence* (Proportion of non-zero sets in the survey)

- Gives an indication of the extent to which the species occupies its traditional area of distribution.
- Should not be interpreted in isolation but rather in conjunction with concentration and local density that together give and indication of the overall distributional characteristics of the species.
- Should be interpreted in conjunction with a map of distribution (cpue or +-).
- Should be interpreted in light of information on distribution of human activities (including fishing) and physical environmental conditions (e.g. T).
- Decreasing in prevalence may be the result of local or general reductions in population numbers. Investigation of where the decreases occurred and whether or not these were associated with human activities or changes in environmental conditions will provide significant insight into population status.
- Boundary conditions for this indicator will likely stem from an examination of historical patterns of prevalence. Relationship between overall population size and prevalence (if present) could be used to set combined population size / prevalence limits. Changes in prevalence should also prompt additional investigations to determine cause (anthropogenic vs. physical Vs biological).

3) *CPUE where present* (local density)

- Gives an indication of how densely the species are packed in areas where they occur.
- Should not be interpreted in isolation but rather in conjunction with concentration and prevalence which together give and indication of the overall distributional characteristics of the species.
- Should be interpreted in conjunction with a map of distribution (cpue or +-).
- Should be interpreted in light of information on distribution of human activities (including fishing) and physical environmental conditions (e.g. T).
- Should be interpreted in light of other estimates of population numbers and should likely be age / size disaggregated.
- Changes in local density may occur as a result of density dependent or density independent phenomena. It is likely that any density dependent effects on the population will have their effect at this scale. Changes in local density may also result from changes in prey density or population reduction as a result of human activities including fishing.
- Boundary conditions for cpue where present will likely result from an examination the relationship between local density and population size (by size class).
- This measure may have utility in tracking commercial catch per unit of effort.

Sensitivity

1) Concentration

- Concentration appears to respond to changes in overall abundance at least as rapidly as the single measure of stratified cpue. The measure appears to be somewhat more stable than stratified cpue.
- Time for management intervention is at least the same as for stratified cpue and perhaps somewhat enhanced given the lower variability of the indicator.

2) Prevalence

- Prevalence and concentration appear to be correlated at least for some species and at sufficiently high proportion of population.

3) CPUE where present

- CPUE where present appears to respond more rapidly to changes in population size than stratified cpue for some species.

Illustrative Examples and Interpretation

1) 4VsW Cod (Figures 1 and 2)

Figures 1 shows both the time trends and interactions of each of the indices of abundance and distribution for 4VsW cod. Figure 2 shows these same data using a 3-year running average to smooth out inter-annual variation.

The trend in stratified numbers has been used as the major index of stock abundance for this resource. Interpretations of these trends are contained in a number of assessment documents. In general this shows that population numbers were relatively high in the early 80s and declined to their lowest observed values between the late 80's and mid 90s where they have remained.

The overall prevalence of cod in the stock area, as indicated by the proportion on non-zero sets in the survey, remained relatively constant at about 75% until about 1991 and then declined to about 45%. This decline indicates that cod became less common in the stock area. The metric says nothing about overall breadth of distribution.

The local density of cod in the stock area, as measured by the average numbers caught in all non-zero sets increased from 1970 to 1981 and then declined until the present. This observation is consistent with the decline in prevalence noted above in that an erosion in cod density would not be manifested in a decline in prevalence until the erosion caused declines to 0 in a significant number of locations.

The proportion of surveyed area containing 75% of the estimated population was relatively stable from 1970 to 1981 and then began an accelerating decline until about 1996. This decline indicates that the population became increasingly confined. This was not associated with an increase in density but indicated a general erosion of population abundance.

The inter-relation between these indices is also shown.

The relationship between stratified numbers and density, prevalence, and concentration, could indicate either a positive non-linear (asymptotic) correlation, or a linear relationship with two distinct temporal phases, one prior to 1991 and one after 1991. A non-linear relationship has intuitive appeal in that it show an initially rapid response of stratified numbers to increased density, increased prevalence, and decreased concentration, and then responds less rapidly as the survey area becomes fully occupied and only density increases.

Density and prevalence, and density and concentration show a reasonably clear asymptotic relationship. As density increases cod become more prevalent because they spread out over the stock area as shown by the decrease in concentration.

Prevalence and concentration show an apparent negative linear relationship. As concentration decreases, prevalence increases.

2) <u>4VW American Plaice (Figures 3 and 4)</u>

For plaice stratified cpue declines from the late 70's to the early 90's. Local density follows much the same pattern as cpue while prevalence is variable but without an apparent time trend. In this case the long-term change in stratified cpue for plaice appears to be the result of a decline in local density rather than a decline in prevalence within the stock area.

3) <u>4VW Herring (Figures 5 and 6)</u>

For herring, a pelagic species that has low catchability to trawl surveys, stratified cpue declines from 1970 to the early 80s and has increased to the present. For herring this increase is the result of increases in local density as well as increased prevalence within the stock area. This indicates that herring are both caught in increasingly greater numbers at an increasing number of locations on the eastern shelf.

It is notable that the decline in cpue during the 70s was mainly the result of a decrease in prevalence since local density remained relatively stable over this period (with the exception of the 1980 point where very few herring were caught).

5) <u>4VW Haddock (Figures 7 and 8)</u>

For eastern Scotian shelf haddock, cpue increased rapidly from the mid 70s to the early 80s declined slowly to the mid 90s and shows some increase in the most recent years. For haddock local density increased rapidly from the mid 1970s to the early 1980s decreased to the mid 80s and has increased since then. Prevalence showed the same increase as both cpue and local density but has declined substantially (from 70% to 45%) between 1982 and 1998. In this case the slow decline in cpue observed was the result of decline in prevalence coupled with slowly increasing local density.

6) Barndoor Skate (Figure 9)

This cpue for this species declined to near 0 during the 1970s but has increased since 1991. The decrease was the result of declines in both local density and prevalence. The increase in cpue began as an increase in prevalence but since 1996 increased local density has also contributed.

7) Thorny Skate (Figure 10)

For thorny skate cpue was variable from the 70 through mid 80s and then decline rapidly to the present low. In this case both local density and prevalence showed nearly monotonic declines since 1975. Prevalence of this species has declined from over 80% to less than 40% over the duration of the survey.

8) Striped Wolffish (Figure 11)

Wolffish cpue increased through the 80s and then declined through most of the 90s. The increase appears to have been the result of concurrent increases in local density and prevalence, while the decline through the 70s is more the result of a decline in prevalence.

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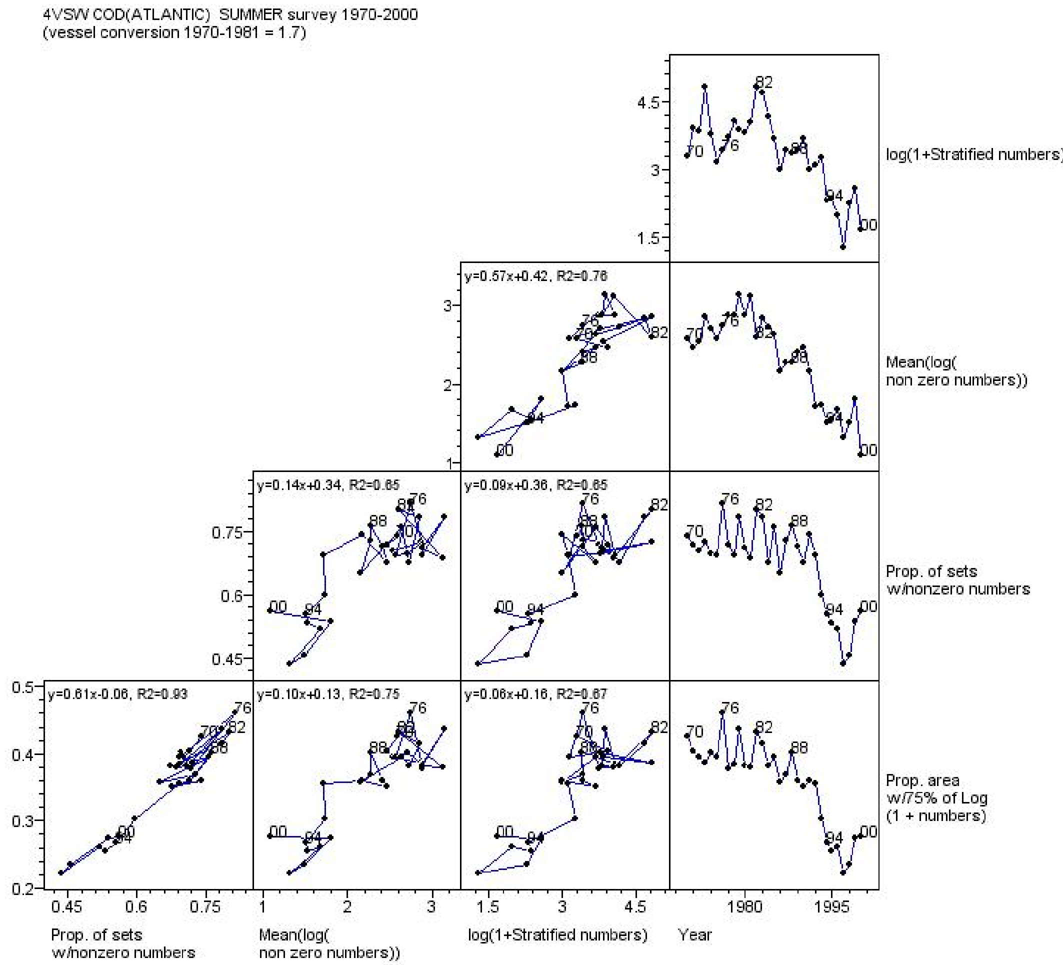

Figure 1. Distributional and abundance indices for 4VsW cod. These indices were estimated from the summer survey results (1970 – 1999) using a 10-minute grid cell to aggregate data except for the stratified numbers, which were estimated according to standard procedures.

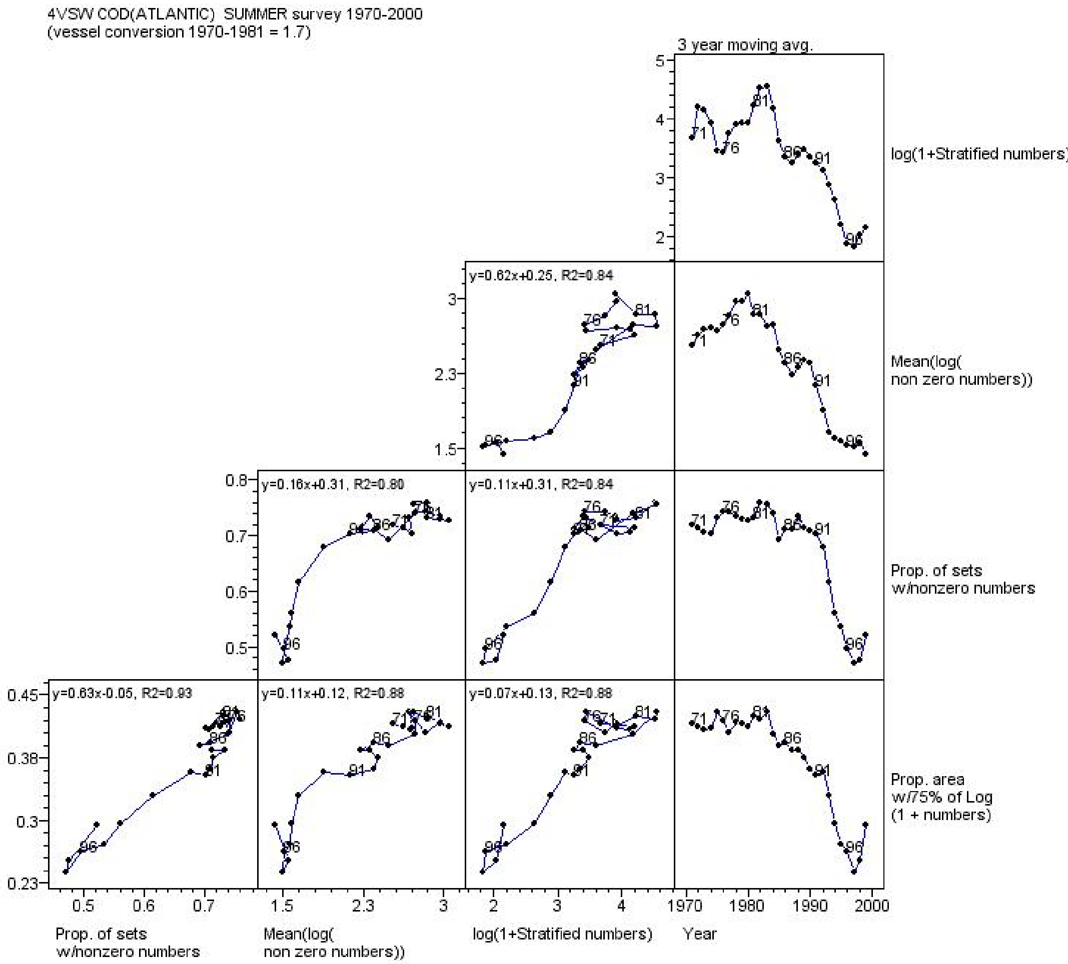

Figure 2. Distributional and abundance indices for 4VsW cod. These indices were estimated from the summer survey results (1970 – 1999) using a 10-minute grid cell to aggregate data except for the stratified numbers, which were estimated according to standard procedures. Temporal trends are expressed as 3-year running means to minimize interannual variation.

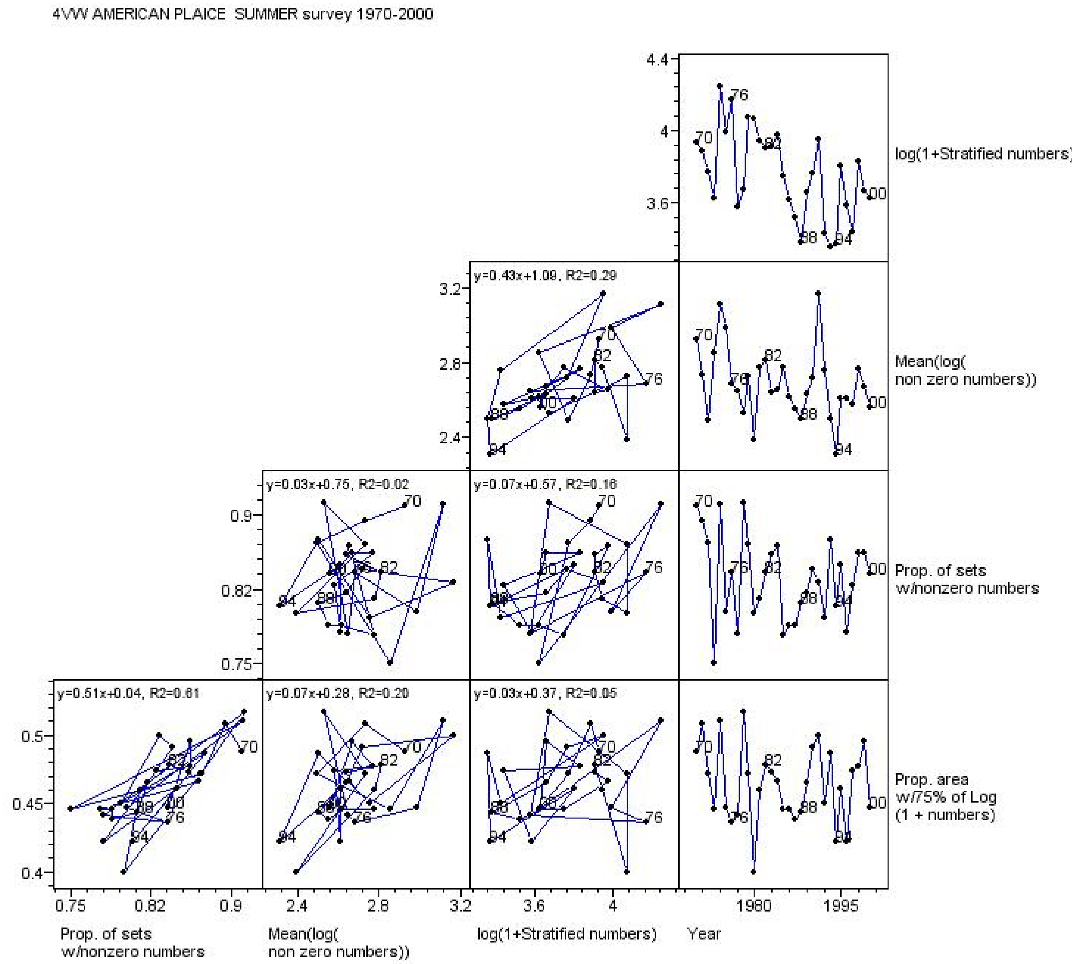

Figure 3. Distributional and abundance indices for 4VW American Plaice. These indices were estimated from the summer survey results (1970 – 1999) using a 10-minute grid cell to aggregate data except for the stratified numbers, which were estimated according to standard procedures.

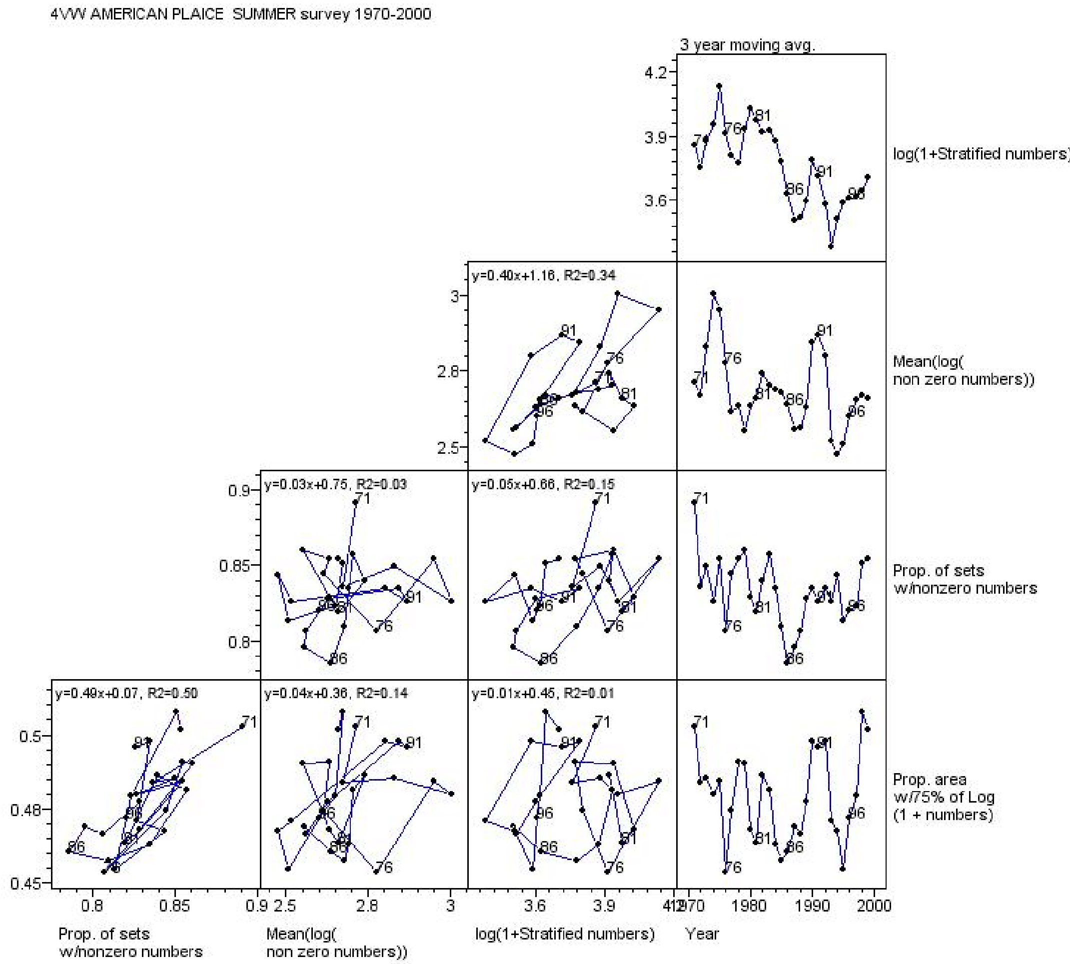

Figure 4. Distributional and abundance indices for 4VW American Plaice. These indices were estimated from the summer survey results (1970 – 1999) using a 10-minute grid cell to aggregate data except for the stratified numbers, which were estimated according to standard procedures. Temporal trends are expressed as 3-year running means to minimize interannual variation.

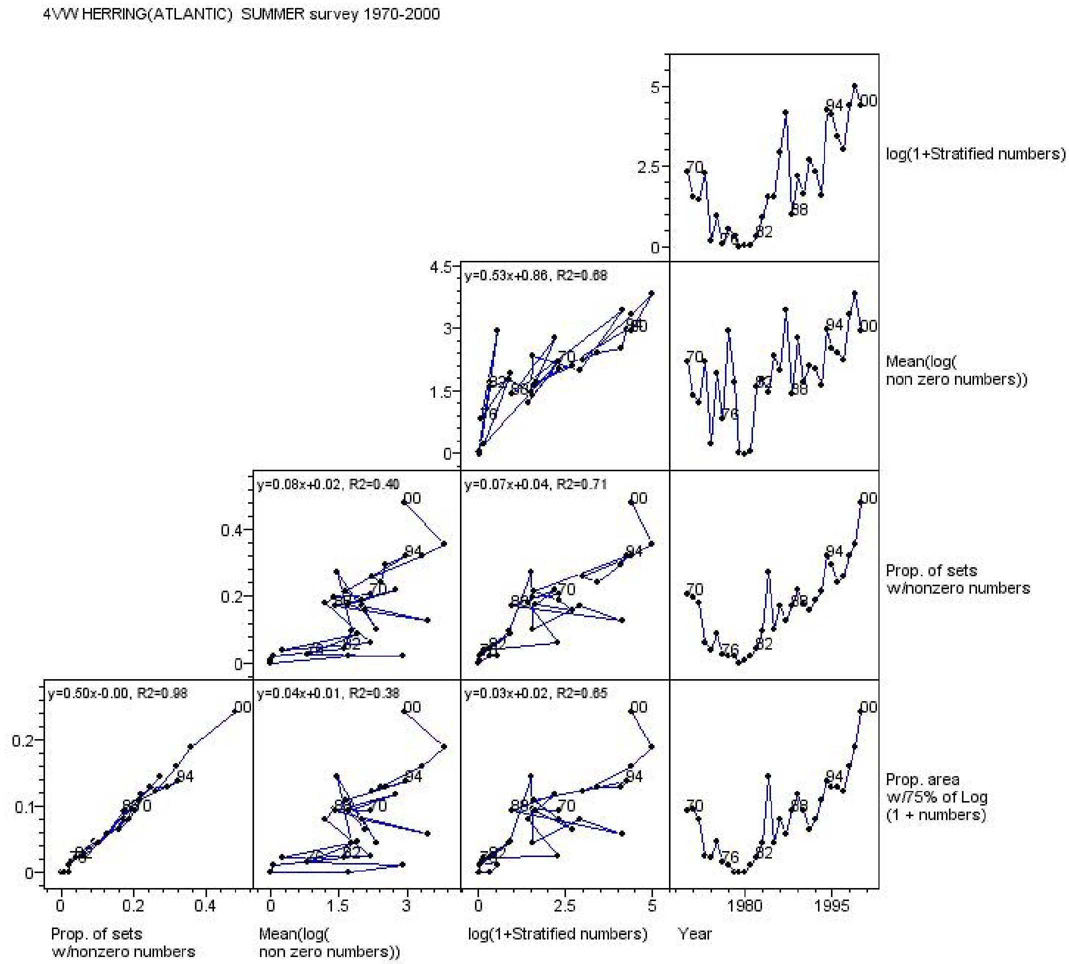

Figure 5. Distributional and abundance indices for 4VW herring. These indices were estimated from the summer survey results (1970 – 1999) using a 10-minute grid cell to aggregate data except for the stratified numbers, which were estimated according to standard procedures.

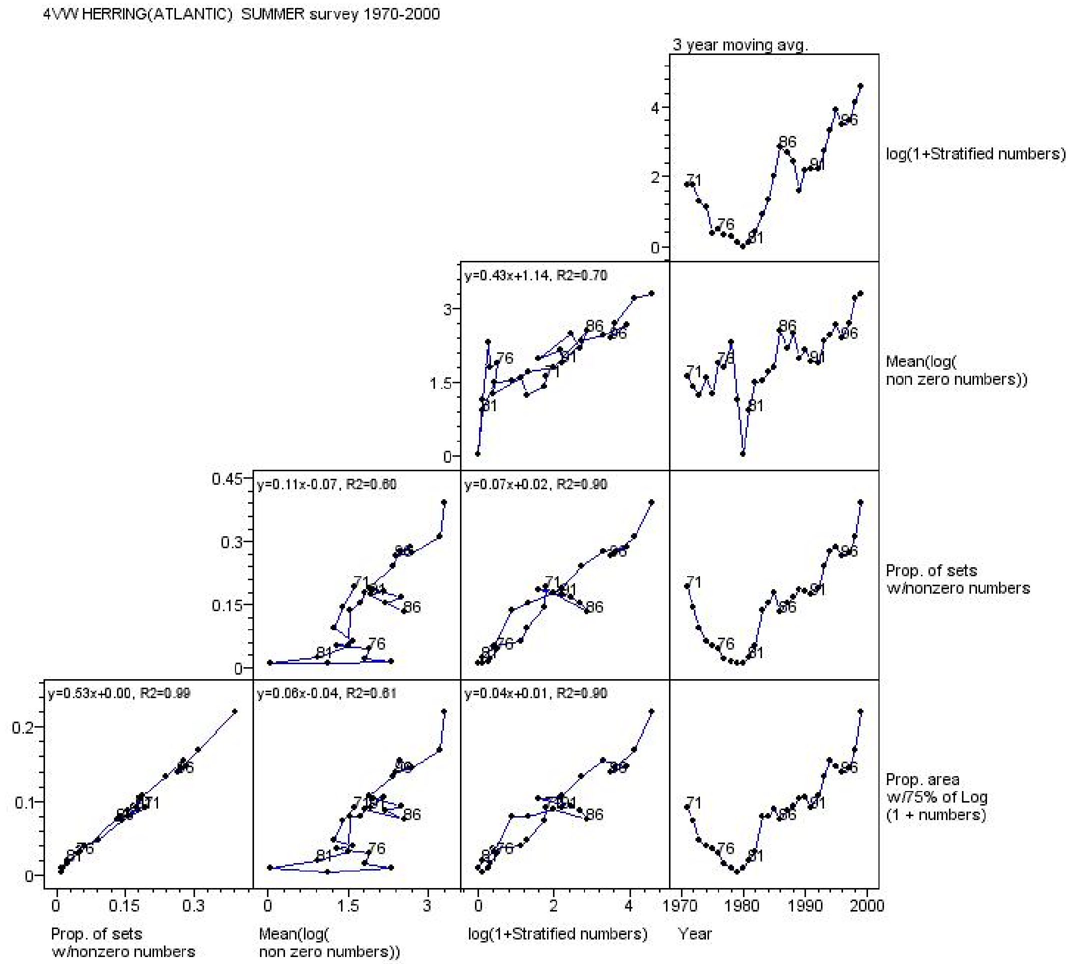

Figure 6. Distributional and abundance indices for 4VW herring. These indices were estimated from the summer survey results (1970 – 1999) using a 10-minute grid cell to aggregate data except for the stratified numbers, which were estimated according to standard procedures. Temporal trends are expressed as 3-year running means to minimize interannual variation.

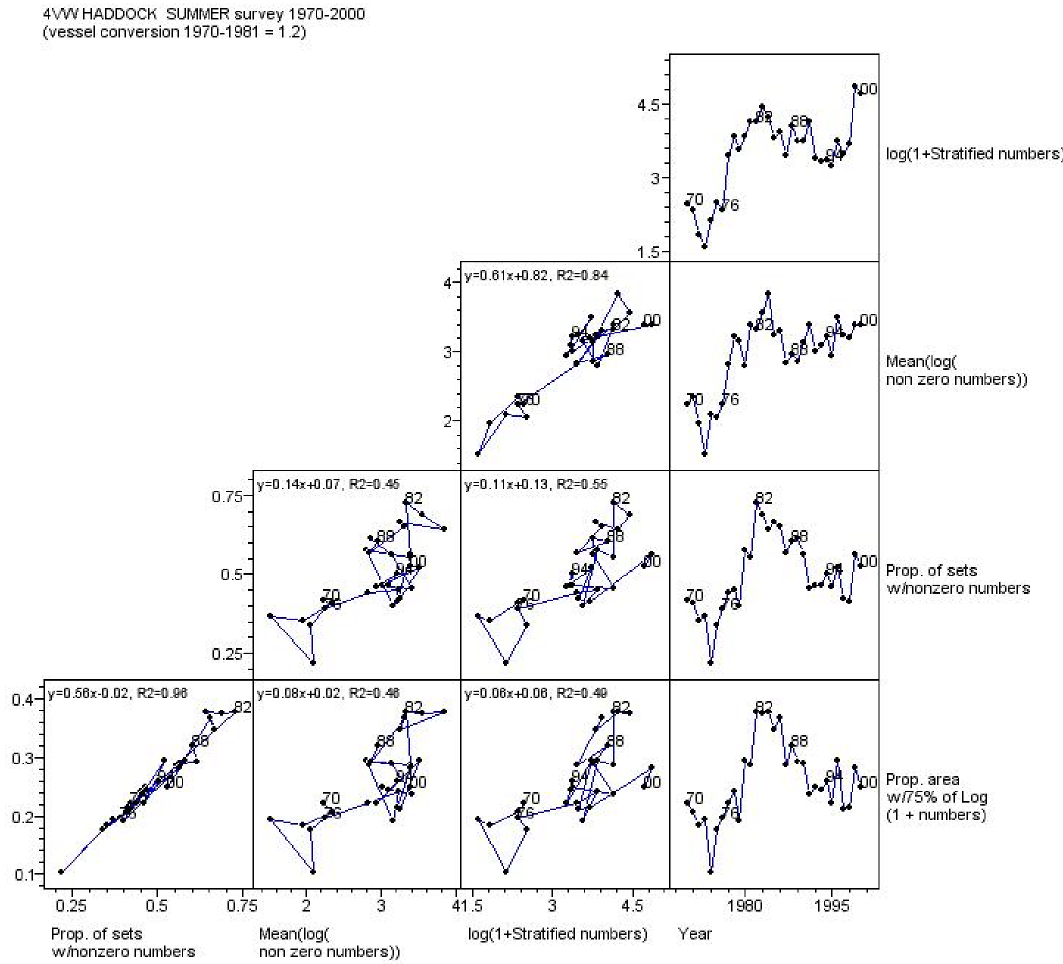

Figure 7. Distributional and abundance indices for 4VW haddock. These indices were estimated from the summer survey results (1970 – 1999) using a 10-minute grid cell to aggregate data except for the stratified numbers, which were estimated according to standard procedures.

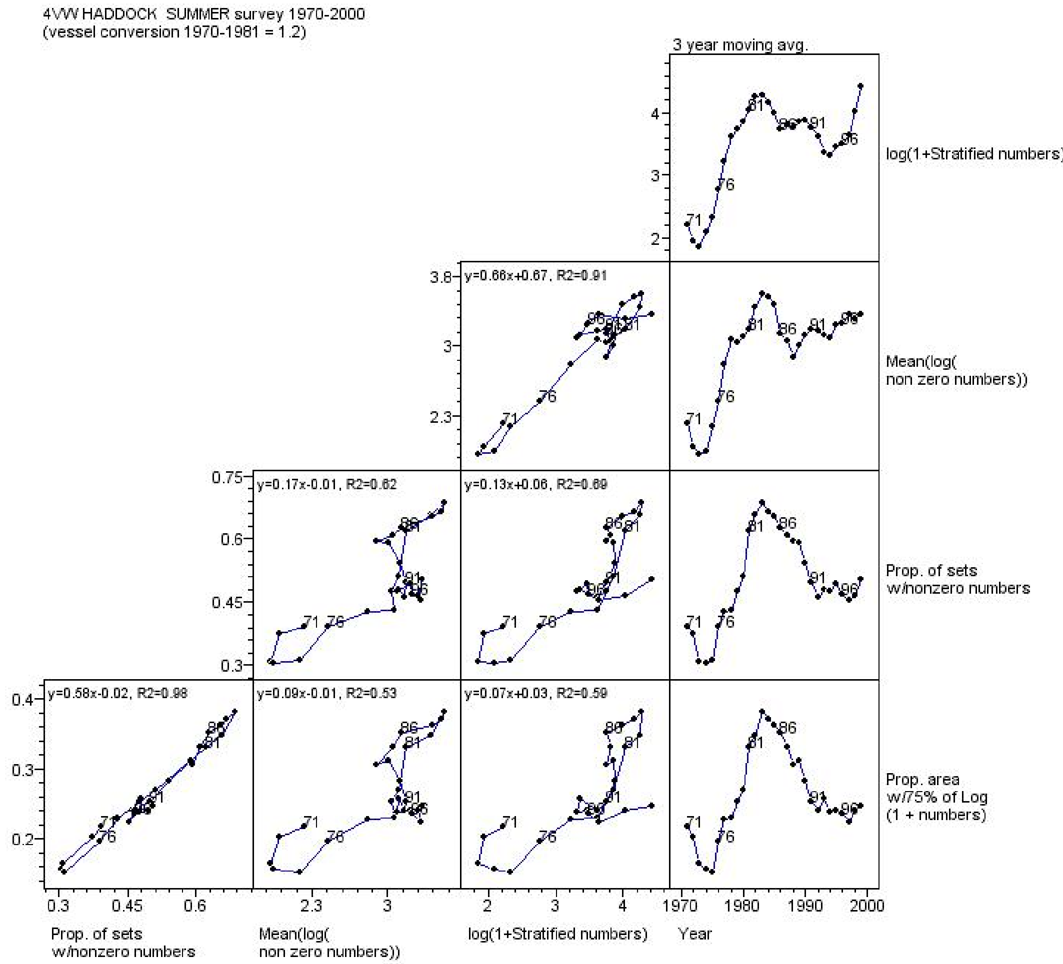

Figure 8. Distributional and abundance indices for 4VW haddock. These indices were estimated from the summer survey results (1970 – 1999) using a 10-minute grid cell to aggregate data except for the stratified numbers, which were estimated according to standard procedures. Temporal trends are expressed as 3-year running means to minimize interannual variation.

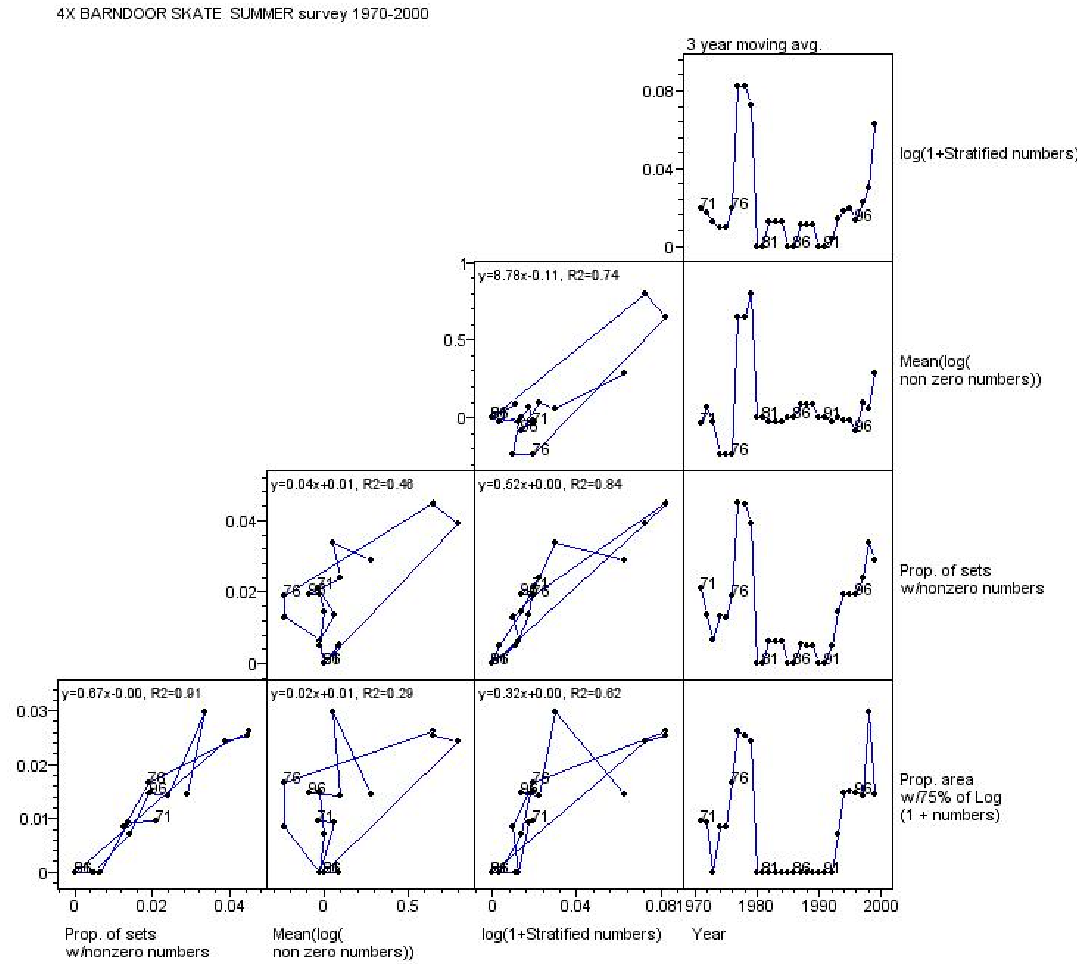

Figure 9. Distributional and abundance indices for 4X barndoor skate. These indices were estimated from the summer survey results (1970 – 1999) using a 10-minute grid cell to aggregate data except for the stratified numbers, which were estimated according to standard procedures. Temporal trends are expressed as 3-year running means to minimize interannual variation.

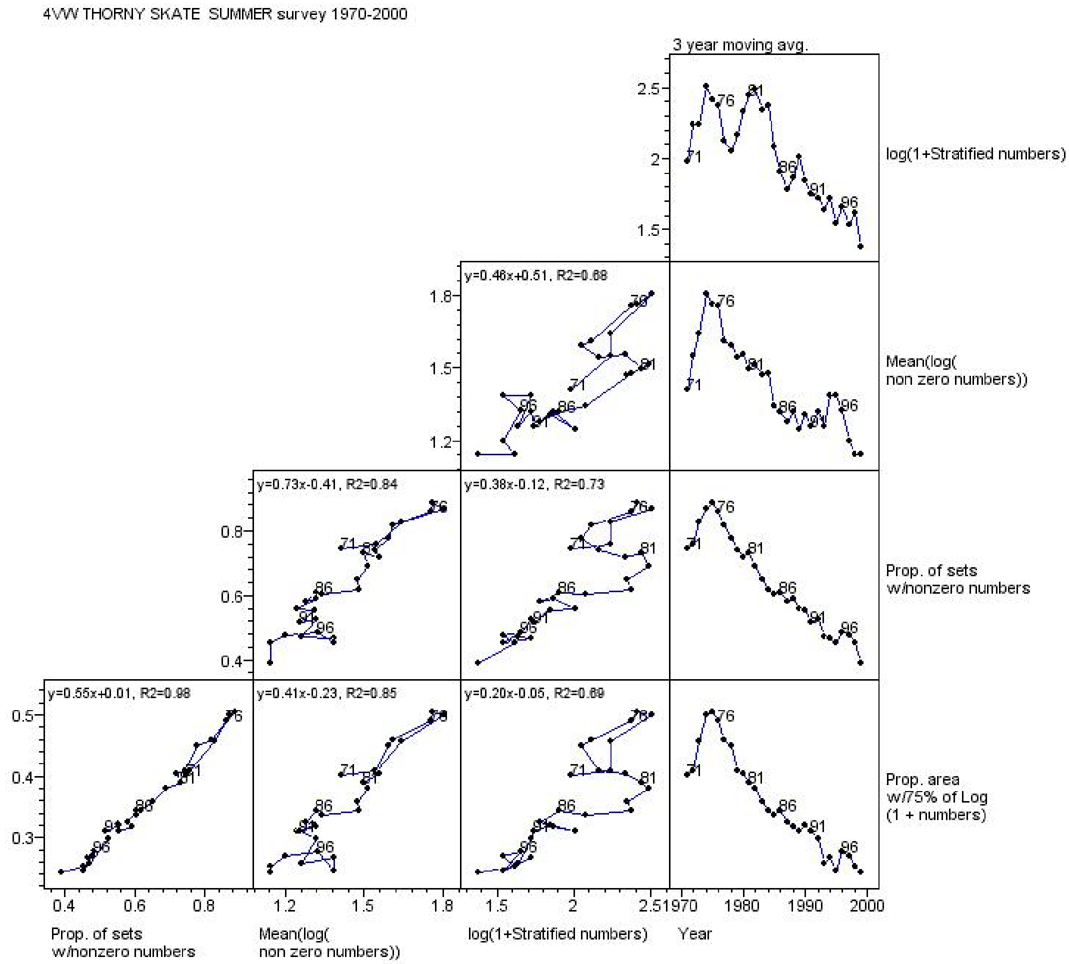

Figure 10. Distributional and abundance indices for 4VW thorny skate. These indices were estimated from the summer survey results (1970 – 1999) using a 10-minute grid cell to aggregate data except for the stratified numbers, which were estimated according to standard procedures. Temporal trends are expressed as 3-year running means to minimize interannual variation.

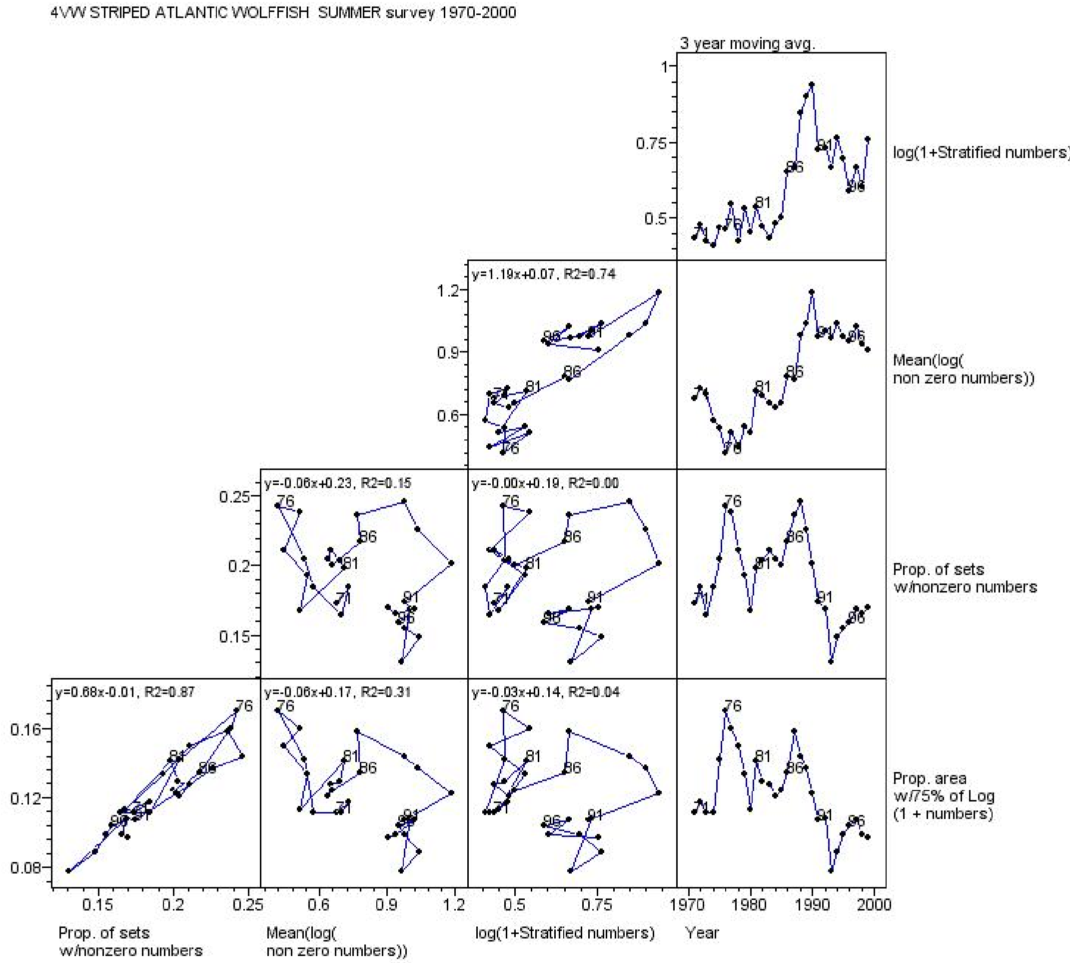

Figure 11. Distributional and abundance indices for 4VW Striped wolffish. These indices were estimated from the summer survey results (1970 – 1999) using a 10-minute grid cell to aggregate data except for the stratified numbers, which were estimated according to standard procedures. Temporal trends are expressed as 3-year running means to minimize interannual variation.