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The Lorenz Curve Method Applied to NEFSC Bottom Trawl Survey Data

by

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This report is a product of the 21st Northeast Regional Stock Assessment Workshop (21st SAW). Proceedings and products of the 21st SAW are scheduled to be documented and released as subissues (denoted by a lower case letter) of *Northeast Fisheries Science Center Reference Document* 96-05 (*e.g.*, 96-05a) . Tentative titles for the 21st SAW are:

An index-based assessment of winter flounder populations in the Gulf of Maine

Assessment of winter flounder in Southern New England and the Mid-Atlantic

Influence of temperature and depth on distribution and catches of yellowtail flounder, Atlantic cod, and haddock in NEFSC bottom trawl surveys

Predicting spawning stock biomass for Georges Bank and Gulf of Maine Atlantic cod stocks with research vessel survey data

Preliminary results of a spatial analysis of haddock distribution applying a generalized additive model

Report of the 21st Northeast Regional Stock Assessment Workshop (21st SAW): Public Review Workshop

Report of the 21st Northeast Regional Stock Assessment Workshop (21st SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments

Stock assessment of northern shortfin squid in the Northwest Atlantic during 1993

The Lorenz curve method applied to NEFSC bottom trawl survey data

Abstract

The Lorenz curve method was applied to Northeast Fisheries Science Center (NEFSC) research vessel survey data to determine changes in the concentration of haddock (*Melanogrammus aeglefinus*) and witch flounder (*Glyptocephalus cynoglossus*) in the Georges Bank - Gulf of Maine region over a 32 year period. Estimated biomass for each species within a strata set area was examined. Since the survey strata area vary in size, a modification to the method was explored and a comparison of methods conducted. Lorenz curves (ordered by mean weight per tow) were calculated for each NEFSC autumn bottom trawl survey between 1963 and 1994. Haddock distribution on Georges Bank has become more concentrated over the study period and there appears to be two phases of increasing concentration, with the later phase higher in concentration than the first. Although changes in concentration of witch flounder biomass have occurred, there is no apparent trend over time.

Introduction

The Lorenz curve is an econometrics method developed to study the distribution of income among individuals (Lorenz 1905, Dagum 1985). Thompson (1976) applied the Lorenz curve in a study of the distribution of fish caught by a population of fishermen (i.e., was it true that 90 percent of the fish were caught by 10 percent of the fishermen?). Myers and Cadigan (1995) applied this method to northern cod biomass off Newfoundland using 76 strata from a 12 year research survey time series. Changes in concentration of flatfish off Newfoundland were also examined by Myers et al. (1995) using this technique. When the technique is applied to fish distributions, the Lorenz curve simultaneously takes into account biomass and area and puts them on a comparable basis. In this paper, the Lorenz curve method was used to examined the distribution of haddock and witch flounder biomass as estimated from NEFSC autumn bottom trawl surveys in the Georges Bank - Gulf of Maine region over a 32 year period.

Methods

As described by Myers and Cadigan (1995), a Lorenz curve is calculated as follows: for a set of n strata, let x_i be the biomass and a_i be the area of stratum i, i=1,2...n, ranked by biomass. The Lorenz curve is the polygon joining the points $(A_h/A_n, L_h/L_n)$, h=(0,1,2 ... n) where $L_0 = 0$ and $L_h = \Sigma^h_{i=1} x_i$ is the total biomass in the h strata with the lowest biomass, and $A_0 = 0$ and $A_h = \Sigma^h_{i=1} a_i$ is the total area of the h strata with the lowest biomass. The x-axis of the Lorenz curve represents the cumulative percentage of area, while the y-axis depicts the cumulative percentage of biomass (Figure 1). If fish are evenly distributed among strata the Lorenz curve would be an identity function (Figure 1). If fish are unevenly distributed (i.e., concentrated) the Lorenz curve bows downward and to the right within the unit square (Figure 1). The Gini index, a common measure of concentration, is derived by doubling the area between the identity function and the Lorenz curve (Dagum 1985).

As formulated above, the Lorenz curve method does not fully account for strata of unequal size. Since the NEFSC survey has a wide range of strata sizes, a modification of the method was explored by ranking strata by mean weight per tow (kg/tow) instead of biomass, and then calculating the cumulative percentage of biomass and area. A comparison of the ranking by biomass and mean weight per tow was conducted for Georges Bank haddock for 1974. Input data for the comparison are given in Table 1. Results for strata ordered by biomass are given in Table 2, and results for strata ranked by mean weight per tow are given in Table 3.

Lorenz curves (ordered by mean weight per tow) were calculated for each NEFSC autumn bottom trawl survey between 1963 and 1994 to determine changes in concentration of Georges Bank haddock and witch flounder in the Gulf of Maine-Georges Bank region. For each species, the strata set used corresponded to that used in the most recent stock assessment. The strata set used for haddock was strata 13-25, 29-30 (O'Brien and Brown 1995) while for witch flounder the strata set comprised strata 22-30, 36-40 (Wigley and Mayo 1994). Biomass values used in the analysis were estimates of minimum swept area biomass (kg) calculated for each stratum in each year. Haddock biomass values were adjusted for differences in fishing power of the *Albatross IV* and the *Delaware II*, and for differences in the catchability of BMV doors and the polyvalent doors introduced to the survey in 1985. The fishing power coefficient of 0.79 and door coefficient of 1.51 were applied to the biomass indices at the stratum level (O'Brien and Brown 1995).

Results

Comparison of Lorenz Curves - The ordering of the data affected the shape of the Lorenz curve and the magnitude of the resulting Gini index. For the 1974 haddock data the Lorenz curve ranked by biomass has a 'stepped' or irregular shape whereas the Lorenz curve ranked by mean weight per tow has a smooth shape (Figure 1). The Gini index for the Lorenz curve ordered by biomass was 0.45 while the Gini Index ordered by mean weight per tow was 0.62. The difference in concentration indices is due to high densities of haddock in some of the smaller strata (i.e., strata 21, 22, and 25; Tables 2 and 3). When ordering by mean weight per tow, the more dense strata are shifted further out on the x and y axes (regardless of the strata size) and the curve becomes more bowed. The slopes between points also constantly increase. Ranking by mean weight per tow disassociates area from biomass since mean weight per tow is independent of stratum size, making this application of the method more in keeping with the original application of income per individual. Additional refinements to this method to address the issue of unequal stratum size are ongoing.

Haddock - Annual Lorenz curve plots (Figure 2) indicate even distributions of haddock over Georges Bank in the early-mid 1960s, with distributions becoming more uneven in the mid-1970s. Haddock distributions are more evenly distributed in the late 1970's and early 1980s, but in subsequent years, haddock distributions are highly uneven (Figure 2). Over the 32 year study period, haddock distribution on Georges Bank has become more concentrated and there appear to be two periods of increasing concentration, with the later phase higher in concentration

than the first (Figure 3). The first period lasting until the early 1970's probably corresponds to the fishing down of the extremely strong 1963 year class. Improved recruitment from the 1975 and 1978 year classes resulted in more uniform distribution patterns during the late 1970's and early 1980's; however, as these cohorts were fished down, the spatial patchiness increased. Overholtz (1985) showed that Georges Bank haddock from the 1975 and 1978 year classes exhibited age-specific distribution patterns, so further analyses are warranted to examine year-class and age class effects on this phenomenon.

Witch flounder - Annual Lorenz curves reveal no obvious trends (Figures 4 and 5). In 1974, 1980, 1985 and 1994, witch flounder biomass was rather evenly distributed over the survey area. While in 1972, 1982, 1989, and 1990 biomass appeared to be more spatially concentrated.

Implications

For species in which temporal changes in concentration occur, changes in catchability (q) to the commercial fishery may also occur. If so, commercial catch rates may not accurately reflect stock abundance without some adjustment of q. For example, if fish concentrate, commercial catch rates may actually to increase when abundance declines. As a consequence, estimates of fishing mortality rates will be underestimated.

Acknowledgments

I wish to thank N. Barrowman of the Northwest Atlantic Fisheries Centre in St. John's Newfoundland for generously supplying the software he developed to calculate the Lorenz curve and concentration index, and all the members of the Northern Demersal Subcommittee, particularly S. Cadrin of the Massachusetts Division of Marine Fisheries, for providing insightful comments on the Lorenz curve analyses.

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Table 1. Input data for Lorenz curves analyses of NEFSC bottom trawl survey data for Georges Bank haddock in 1974. Area is in square nautical miles.

Stratum	Area	Percent Area	Biomass kg	Percent Biomass	Mean Weight (kg) per tow
13	2374	12.4	0	0.0	0.00
14	656	3.4	0	0.0	0.00
15	230	1.2	0	0.0	0.00
16	2980	15.5	749967	9.8	2.52
17	360	1.9	93771	1.2	2.60
18	172	0.9	31166	0.4	1.81
19	2454	12.8	0	0.0	0.00
20	1221	6.4	0	0.0	0.00
21	424	2.2	565012	7.4	13.33
22	454	2.4	1134569	14.8	24.99
23	1016	5.3	770148	10.1	7.58
24	2569	13.4	2586132	33.8	10.07
25	390	2.0	519704	6.8	13.33
29	3245	16.9	1194363	15.6	3.68
30	619	3.2	15578	0.2	0.25
Total	19164	100.0	7660410	100.0	

Table 2. Input data for Lorenz curve analysis of 1974 Georges Bank haddock from the NEFSC autumn bottom trawl survey, **ordered by biomass**. Area is in square nautical miles.

Stratum	Area	Percent Area	Biomass kg	Percent Biomass	Mean Weight (kg) per tow	Cumulative % Area	Cumulative % Biomass
19	2454	12.8	0	0.0	0.00	12.81	0.00
20	1221	6.4	0	0.0	0.00	19.18	0.00
14	656	3.4	0	0.0	0.00	22.60	0.00
13	2374	12.4	0	0.0	0.00	34.99	0.00
15	230	1.2	0	0.0	0.00	36.19	0.00
30	619	3.2	15578	0.2	0.25	39.42	0.20
18	172	0.9	31166	0.4	1.81	40.32	0.61
17	360	1.9	93771	1.2	2.60	42.19	1.83
25	390	2.0	519704	6.8	13.33	44.23	8.62
21	424	2.2	565012	7.4	13.33	46.44	15.99
16	2980	15.5	749967	9.8	2.52	61.99	25.78
23	1016	5.3	770148	10.1	7.58	67.29	35.84
22	454	2.4	1134569	14.8	24.99	69.66	50.65
29	3245	16.9	1194363	15.6	3.68	86.59	66.24
24	2569	13.4	2586132	33.8	10.07	100.00	100.00
Total	19164	100.0	7660410	100.0			

Gini Index = 0.45

Table 3. Input data for Lorenz curve analysis of 1974 Georges Bank haddock from the NEFSC autumn bottom trawl survey, **ordered by mean weight per tow**. Area is in square nautical miles.

Stratum	Area	Percent Area	Biomass kg	Percent Biomass	Mean Weight (kg) per tow	Cumulative % Area	Cumulative % Biomass
19	2454	12.8	0	0.00	0.00	12.81	0.00
14	656	3.4	0	0.00	0.00	16.23	0.00
13	2374	12.4	0	0.00	0.00	28.62	0.00
15	230	1.2	0	0.00	0.00	29.82	0.00
20	1221	6.4	0	0.00	0.00	36.19	0.00
30	619	3.2	15578	0.2	0.25	39.42	0.20
18	172	0.9	31166	0.4	1.81	40.32	0.61
16	2980	15.5	749967	9.8	2.52	55.87	10.40
17	360	1.9	93771	1.2	2.60	57.74	11.62
29	3245	16.9	1194363	15.6	3.68	74.68	27.22
23	1016	5.3	770148	10.1	7.58	79.98	37.27
24	2569	13.4	2586132	33.8	10.07	93.38	71.03
21	424	2.2	565012	7.4	13.33	95.60	78.40
25	390	2.0	519704	6.8	13.33	97.63	85.19
22	454	2.4	1134569	14.8	24.99	100.00	100.00
Total	19164	100.0	7660410	100.0			

Gini Index = 0.62

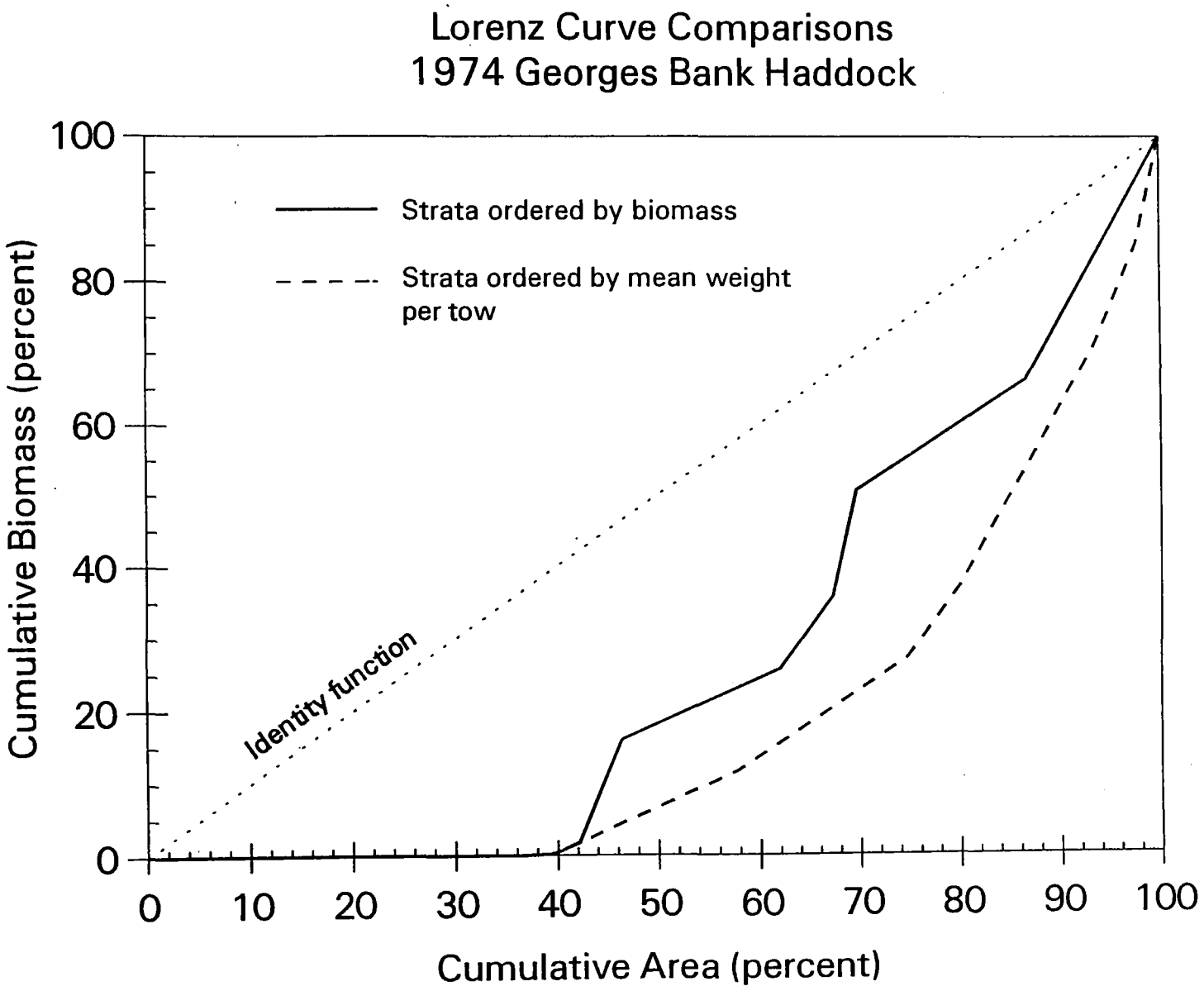

Figure 1. A comparison of Lorenz curves for Georges Bank haddock.

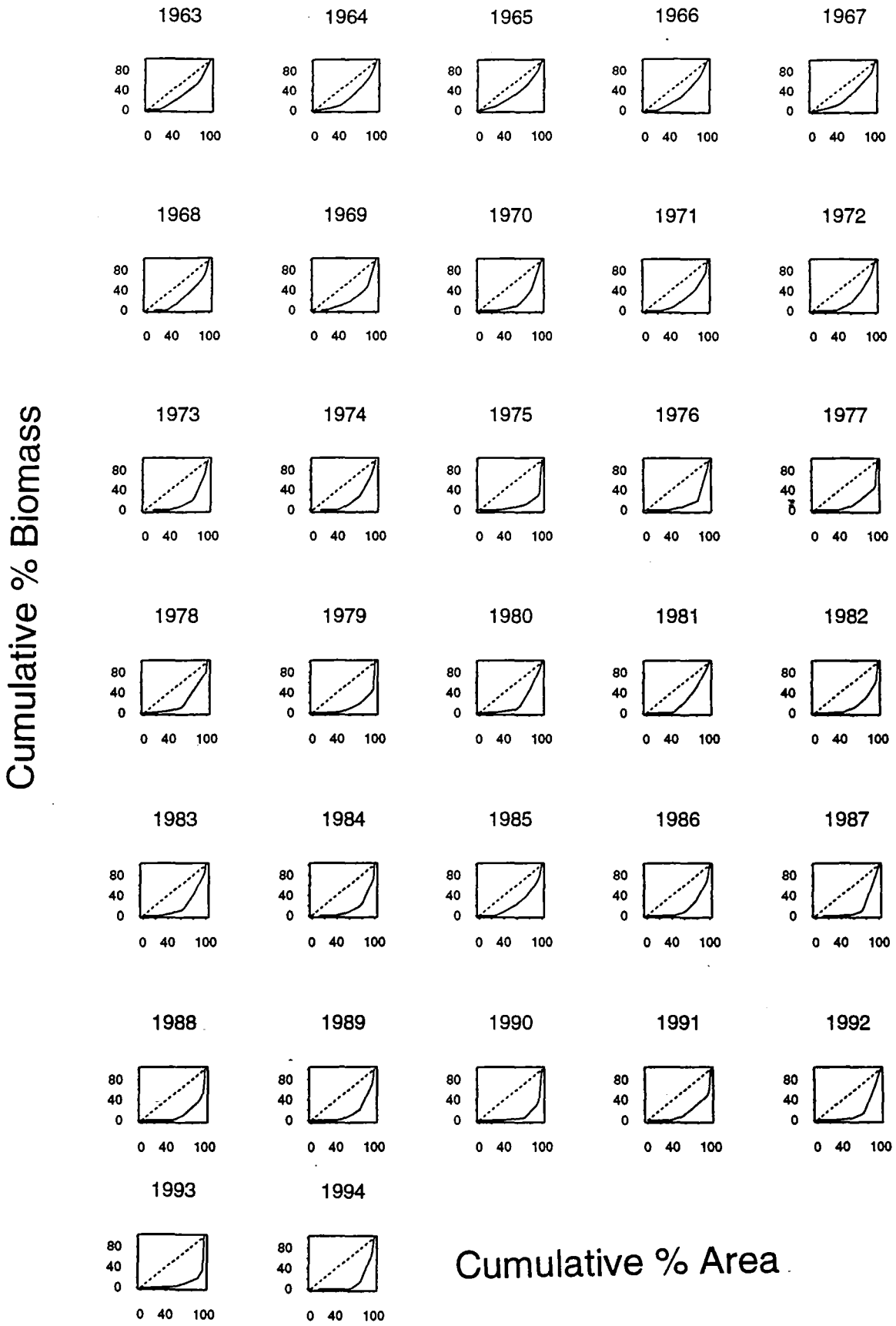

Figure 2. Lorenz curves (ordered by mean weight per tow) for Georges Bank haddock from 1963 to 1994.

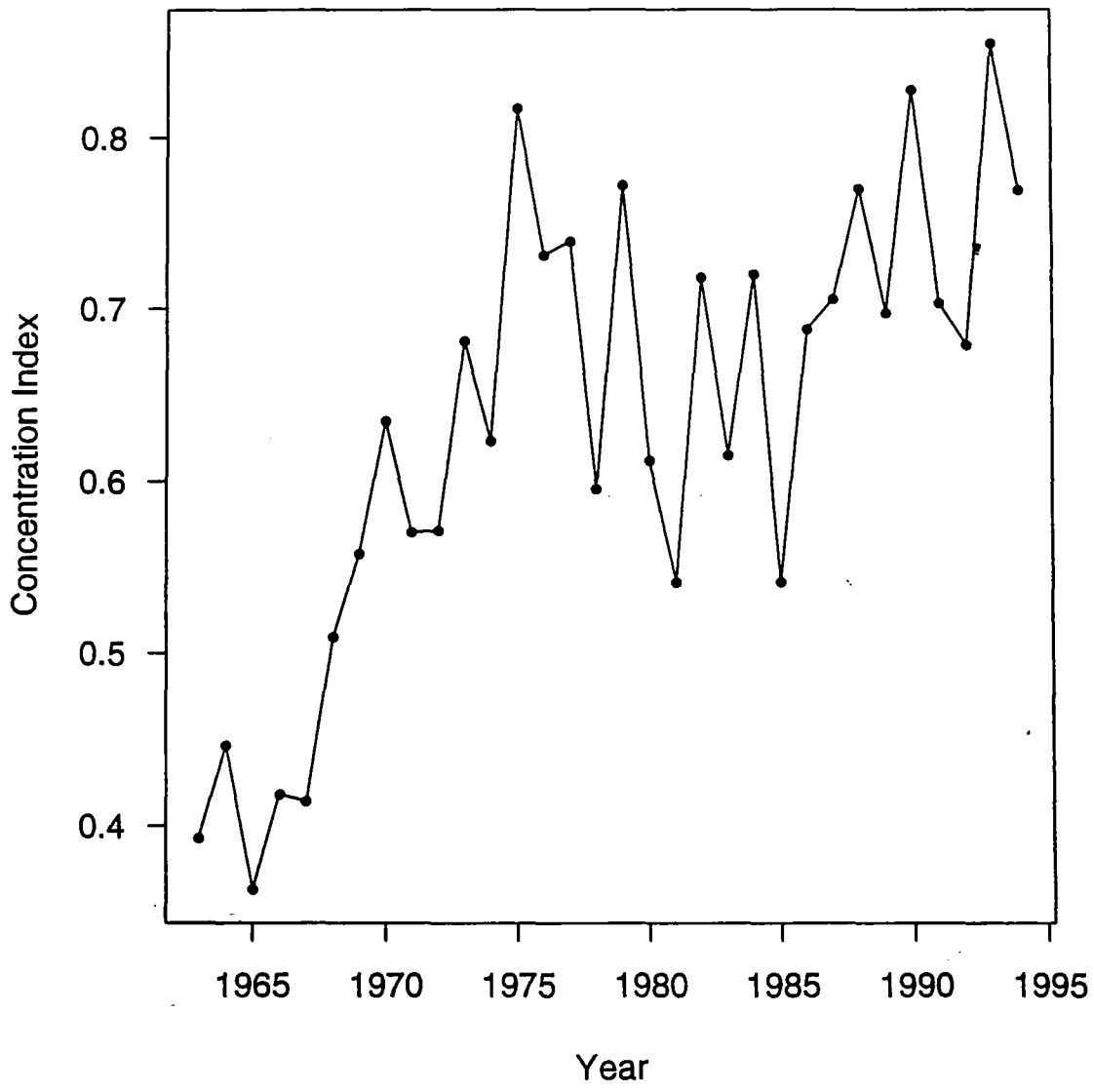

Figure 3. Gini index for Georges Bank haddock from 1963 to 1994.

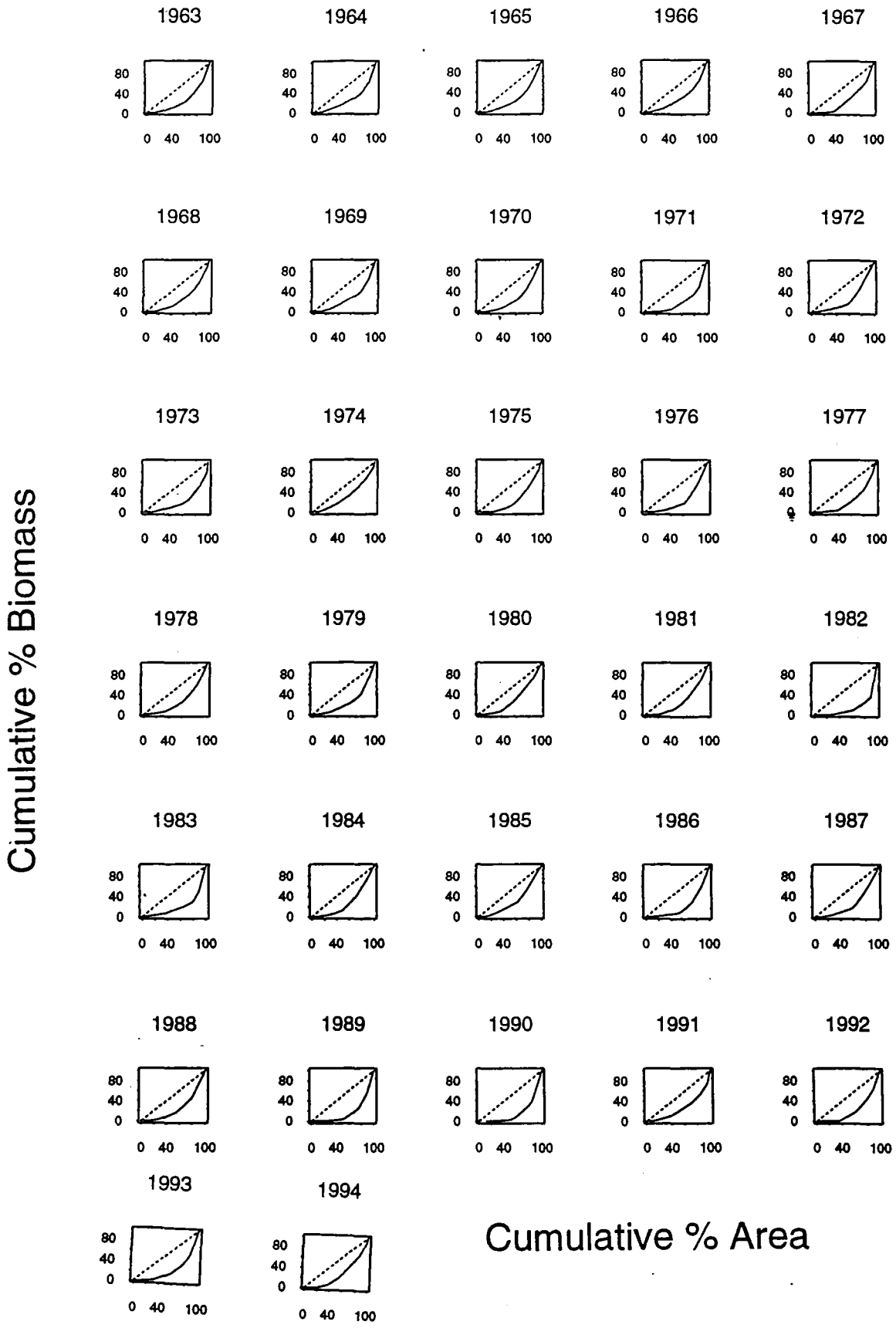

Figure 4. Lorenz curves (ordered by mean weight per tow) for witch flounder in the Gulf of Maine-Georges Bank region from 1963 to 1994.

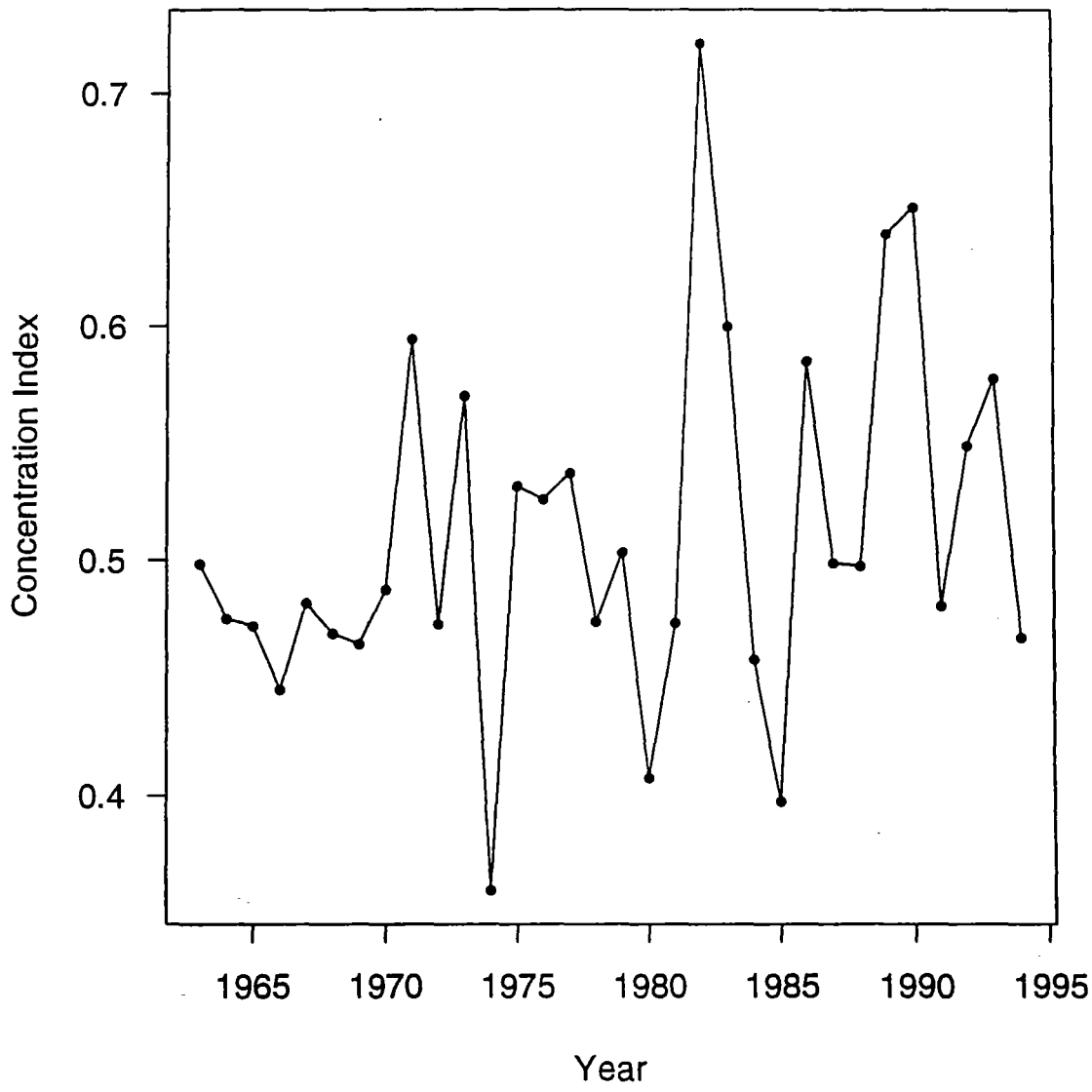

Figure 5. Gini index for witch flounder in the Gulf of Maine-Georges Bank region from 1963 to 1994.