Northwest Atlantic Fisheries Organization

Serial No. N2877 NAFO SCR Doc. 97/43

SCIENTIFIC COUNCIL MEETING - JUNE 1997

Associations Between 2J3KL Fall Survey Catches of Cod and Bottom Temperature

by

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Abstract

We calculate the temperature cumulative distributions weighted by the catch of cod from fall surveys in Div. 2J3KL for the period 1981-94 and compare these with the cumulative distributions of sampled temperatures. Bottom temperatures were warm in 1981, then they cooled until 1984, warmed until 1986, and then cooled until about 1992. The association of cod and temperature differed over this period. During the first cold period cod were associated with colder temperatures whereas during the second cold period cod were associated with warmer temperatures. Several hypotheses about the association of cod and temperature are discussed; however, at this point the only conclusion that can be drawn from the data is that cod caught at trawl sites are not randomly distributed with respect to sampled bottom temperatures.

1 Introduction

Associations between catches of cod and bottom temperatures in 2J3KL fall surveys during 1981-1994 are investigated using catch weighted cumulative distributions (Perry and Smith, 1994). These associations are of interest because they may allow us to explain past changes in fish patterns of abundance over the survey area and to predict future changes in response to temperature. They can also potentially affect the comparability of survey relative abundance estimates over time.

Temperature associations have been demonstrated in other regions. Sinclair (1992) found that older cod were located at deeper depths and colder temperatures than younger cod in summer research surveys in 4Vs and 4W. Swain and Kramer (1995) found that cod in 4T September research surveys exhibited temperature preferences and that the strength of the preferences varied from year to year. They found that younger fish generally selected warmer water temperatures than older fish. Cod in 4T tended to select colder water temperatures at higher levels of abundance.

Water mass characteristics have also received attention in terms of its relationship with stock abundance. Smith *et al* (1991) examined fall and spring research surveys results for the Scotian Shelf. Catches of age four cod occurred proportionately more in the cold intermediate layer (CIL) than in other water types. In addition, the largest catches of cod from each survey were always associated with this water mass. Smith and Page (1996) found significant correlations in estimated annual abundance of cod in 4Vs and 4W and the proportion of the survey area containing the CIL for depths of 0-150 meters. After correcting for the CIL effects in the research survey time series, Smith and Page (1996) found a clearer cohort *signal* in the survey abundance indices.

In this paper we calculate the temperature cumulative distributions weighted by the catch of cod from the fall survey in Div. 2J3KL for the period 1981-94 and compare these with the cumulative distributions of temperature available in the sampled areas as recorded by the net-mounted CTD or, where not available, by BT or XBT. Differences in the cumulative distributions can be interpreted as habitat "selection" in a naive sense, but do not necessarily imply active selection of particular habitat types by cod. For example, if the mortality rate of cod is higher in a particular habitat, this would appear as a negative association with this habitat type. As a second example, cod may not select for temperature but may select a habitat on the basis of abundance of a prey species that varies depending on temperature.

Catch weighted cumulative distribution function

What follows is a brief description of the catch weighted cumulative distribution function (CWCDF) that is used for detecting covariate associations (see Perry and Smith, 1994). We restrict our attention to the stratified random sampling design. Let y_{hi} denote either the number or weight caught in the ith tow in stratum h, and let x_{hi} denote the value of the covariate x for the same tow, $i = 1, ..., n_h$, $h = 1, ..., H$. Let N_h denote the total number of possible tow sites in strata h, and let $n = \sum_{h=1}^{H} n_h$ and $N = \sum_{h=1}^{H} N_h$. The design based CDF for x is

$$f(t) = \sum_{h=1}^{H} \frac{N_h}{N} \left[\sum_{i=1}^{n_h} I(x_{hi}) \right] / n_h,$$

where

$$I(x) = \begin{cases} 1, & \text{if } x \leq t, \\ 0, & \text{otherwise.} \end{cases}$$

The design based CWCDF for x is

$$g(t) = \sum_{h=1}^{H} \frac{N_h}{N} \left[\sum_{i=1}^{n_h} \frac{y_{hi}}{\bar{y}_{st}} I(x_{hi}) \right] / n_h,$$

where $\bar{y}_{st}$ is the stratified weighted average of the y_{hi}'s.

The CWCDF is used to show the range of x values for which cod occur; that is, if large y_{hi} are consistently associated with similar values for x_{hi} then that indicates a habitat preference for the level of the x_{hi}'s. Such associations will appear as large discrepancies in $|f(t) - g(t)|$. Conversely, if $f(t) \doteq g(t)$ then that indicates a homogeneous distribution of catches over the levels of x. Perry and Smith (1994) give a more detailed discussion of this diagnostic, including some inference results.

2 Description of distributions

2.1 Observations for combined years

Cumulative distributions (CDFs) of bottom temperatures at trawl stations in the 2J3KL research survey for the period 1981-94 are presented in Fig. 1a. This figure shows that bottom temperatures in 3K are somewhat warmer than in 2J, but substantially colder in 3L. The 50th percentile in 3L is -0.6° C compared with 2.2° C in 3K. This is presumably due to a greater impact of the CIL on the bottom in the shallower waters of 3L, compared with the deeper water of 2J and 3K.

Abundance and biomass weighted CDFs for the period 1981-94 are presented in Fig. 1b. They are similar to each other, in most instances. There is considerable difference in the thermal association in the 3 divisions. In 2J cod appear randomly distributed with respect to bottom temperature, whereas in both 3K and 3L there is evidence of considerable selection for warmer water. This selection is reflected in the CDFs for 2J3KL combined as well. The selection is greatest in 3L where there is a maximum difference of 0.35° C for abundance weighted CDF and 0.37° C for the biomass weighted CDF compared to the unweighted temperature CDF. Despite the observation that there is considerable selection in 3L, cod in this division are still in colder water than those in 2J and 3K. The weighted 50th percentile is about 1° C in 2J, about 2.8° C in 3K, and only about 0.5° C in 3L.

Note that the combined CDFs are not averages of the annual CDFs. The combined CDFs will give more weight to years with relatively large sample sizes.

2.2 Yearly observations for 2J3KL

Prior to 1987, catches of cod were most associated with warm water in 1981 and 1986 (Fig. 2a). These were relatively warm years during the 1981-94 period. This can be seen in Fig. 2b in that the annual unweighted temperature CDF for 1981 and 1986 is somewhat below the CDF calculated for all years. Also, these are the years with the highest median temperatures at trawl sites, 1.6° C and 1.7° C respectively. The area of the CIL (see Fig. 2d) in 1981 and 1986 were the lowest values for the period. In contrast, in 1984 cod appeared to select relatively cold water at the range of available temperatures above 1° C (Fig. 2a). The temperature CDF for this year lies above the combined CDF (Fig. 2b) and the median temperature of 0.4° C is the lowest in the time series (Fig. 2c). The plot of area of the CIL (Fig. 2d) confirms that this was the coldest year in the time series.

The 1981, 1984 and 1986 associations between cod abundance and bottom temperature do not make intuitive sense. Why should cod seek warmer water in warm years and colder water in cold years?

Since 1988 a decrease in the median temperature for survey sites has occurred, to a minimum in 1993 (Fig. 2c). This corresponds with a period of elevation in the area of the CIL (Fig. 2d). Over this cool period the association between cod and bottom temperature at trawl sites appeared to be quite different from that which occurred in 1984. Cod showed an increasing selection for warm water, peaking in 1991 (Fig. 2a) when the area of the CIL was near its highest level (Fig. 2d). For the last three years of the series the degree to which warm water was selected by cod decreased each year (Fig. 2a), corresponding to decreasing area of the CIL (Fig. 2d) and a levelling of the median temperature.

Relatively large catches of cod during the period 1989-94, represented by jumps in the catch weighted CDFs, tend to occur for tows in which the bottom temperature is greater than 2° C.

2.3 Yearly observations for each Division

The relatively small departures from the unweighted CDF noted for 2J in the combined catch weighted CDFs for the period 1981-94 (Fig. 1b) result from averaging out considerable year to year variation in temperature selection in this division (Fig. 3a). Warm water selection is apparent in 1990, 1991 and 1994, whereas cold water selection is apparent in 1983, 1984, and to a lesser extent in 1985. Temperatures were anomalously warm at trawl sites in 1981, 1986 and 1988 and anomalously cold in 1984 (Fig. 3b). Larger catches of cod at low temperatures (<2° C) appear to occur relatively more often in 2J than in 3K and 3L (see below).

There is little evidence of temperature selection by cod in 3K until 1989 (Fig. 4a). In 1989 to 1992 cod show considerable selection for warmer water, reaching a peak in 1990-1991. Cod were associated with cold water more than usual in 1982, 1984 and 1985, and more associated with warm water than usual in 1989-92 (Fig. 4b). The associations occurred despite relatively small departures in bottom temperatures from their combined CDF. Temperatures were, however, somewhat colder than usual in 1985 and slightly colder in 1990, 1992, and 1993.

In 3L substantial temperature selection is apparent in all years except 1984 and 1994 (Fig. 5a). The comparison with the combined unweighted CDF does not indicate why there is no temperature selection in these two years (Fig. 5b). The warm water selection by cod in 1986, 1988, 1989, 1992 and 1993 was substantially more than for the whole 1981-94 period (Fig. 5b). Of these years, 1986 was somewhat warmer than the overall 1991-94 period and 1993 somewhat colder.

3 Discussion

The unweighted CDFs indicate considerable changes in bottom temperature at trawl sites between 1981 and 1994. Temperatures were warm at the start of the time series, then they cooled until 1984, warmed until 1986, and then cooled until about 1992. The first cold period was more pronounced in 2J. The second cold period was more pronounced in 3L and absent in 2J. Relatively less change occurred in 3K. The association of cod with temperature differed over this period. During the first cold period cod were associated with colder temperatures whereas during the second cold period cod were associated with warmer temperatures. This agrees with the hypothesis by Swain and Kramer (1995) that cod will select relatively cold temperatures at high levels of abundance and warmer water at low levels of abundance.

These ideas are in keeping with the basin model of MacCall (1990), but the observations could also be compatible with explanations other than density dependent habitat selection. Substantial changes in the age composition of cod encompassing the two cold periods have occurred and age specific changes should therefore be examined in future studies. There have also been spatial shifts in cod distribution that may not be directly related to temperature. Rose *et al.* (1994) noted that cod in the fall surveys were located to the north during warm periods and to the south during cold periods. Under the density dependent hypothesis, it would therefore be expected that in cold periods the density dependent effect would be more evident in 3L than in 2J. However, in the 1984 cold period cod were randomly distributed with respect to temperature in 3L but associated with colder water in 2J.

Atkinson *et al.* (1997) noted that the area occupied by cod was positively correlated with stock abundance. When more abundant, the stock occupied a larger area, and the area decreased as the stock declined. This same analysis suggested southward and offshore spatial shifts in the 2J3KL cod stock since 1988. Warren (1997) suggests that there was a breakdown in the spatial structure of cod stocks in 2J3KL coincident with the decline in abundance and he conjectured that this could be a consequence of declining availability of prey species. Frank *et al.* (1996) have noted recent dramatic changes in the distribution of capelin, the main prey species for cod. In particular, there was an abrupt decline in offshore abundance in 2J3KL associated with cold temperatures. This may have had an effect on the distribution of cod.

The recent cod-temperature associations are likely not related to changes in trawl catchability. If cod are caught more easily in cold water than in warm water then this would appear as cold water selection, which is opposite to what is observed in the 1990s.

We have assumed throughout our analyses that differences in CDFs and CWCDFs are inferentially equivalent in all years. This may not be the case. In particular, differences may depend on $\bar{y}_{st}$, being less significant for smaller $\bar{y}_{st}$.

The reason for the very different response by cod to the first and second cold water periods in the time series requires further investigation. At this point the only conclusion that can be drawn from the data is that cod caught at trawl sites are not randomly distributed with respect to bottom temperature. There is evidence of substantial habitat selection based on temperature but this selection is complicated by some other variable.

References

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Appendix: Figures

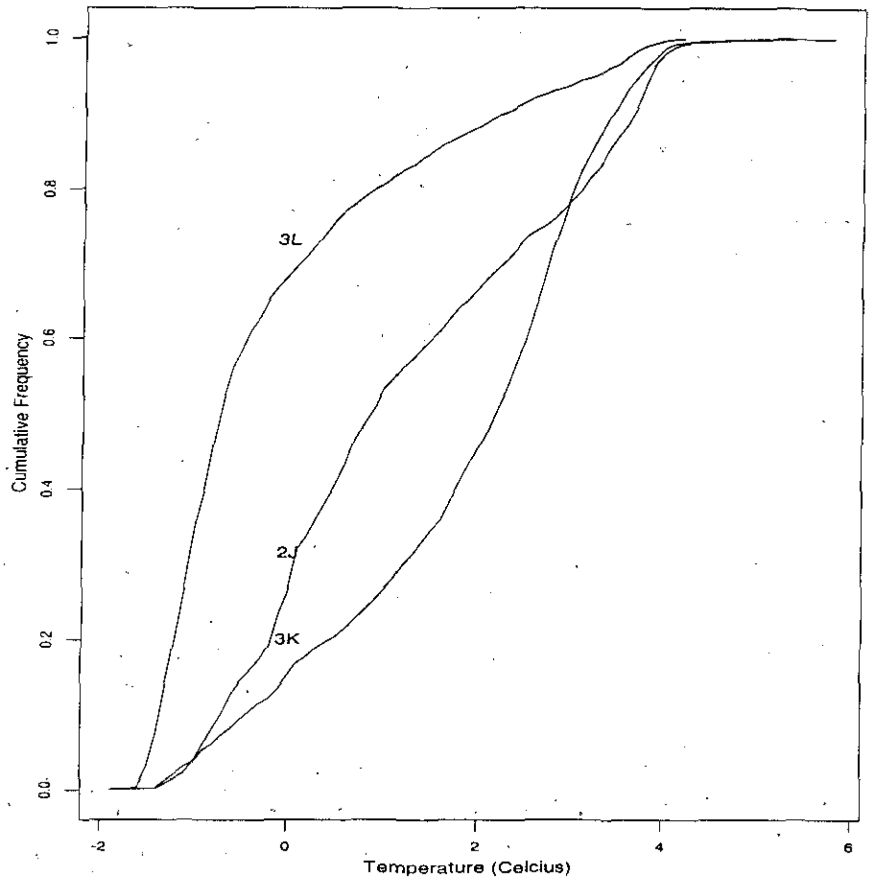

Figure 1a. Bottom temperature cumulative frequency distributions by Division in the 2J3KL trawl fall survey during 1981-1994

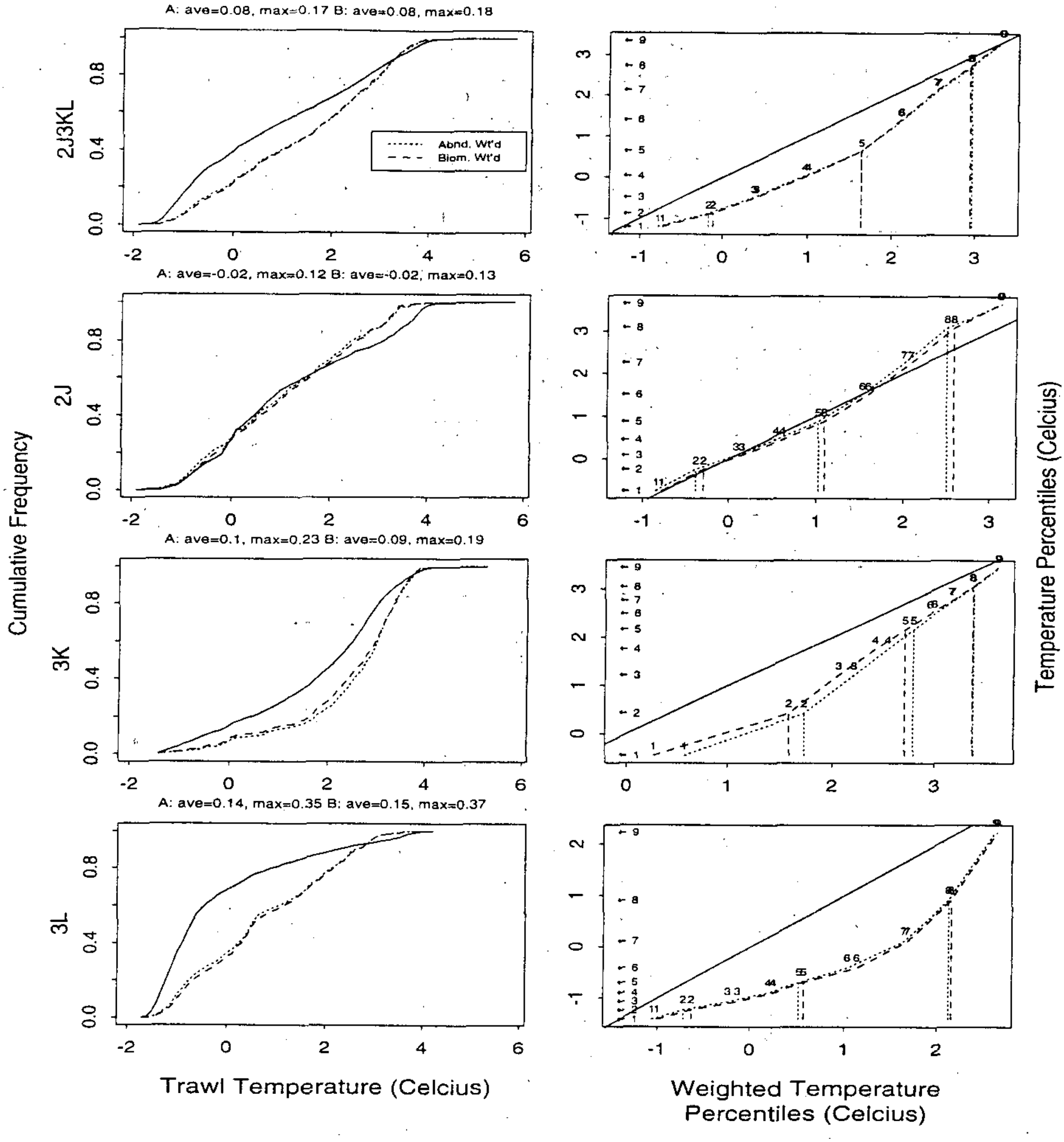

Figure 1b. Cod abundance (numbers per tow) and biomass (tow weights) weighted and unweighted bottom temperature cumulative frequency distributions for the 2J3KL trawl fall survey during 1981-1994. The unweighted CDF is plotted as a solid line and the weighted CDFs are plotted as broken lines in the left panels. The average difference in a weighted and unweighted CDF is denoted by **ave**, while the maximum absolute difference is denoted by **max**. Weighted percentiles are plotted versus unweighted percentiles in the right panels. The solid line denotes a 1:1 relationship. The $(x \times 10)$th percentiles, $x = 1, ..., 9$ are plotted as x's. Vertical lines are plotted for the 20th, 50th, and 80th weighted percentiles. The unweighted temperature percentiles are plotted as $\leftarrow$'s.

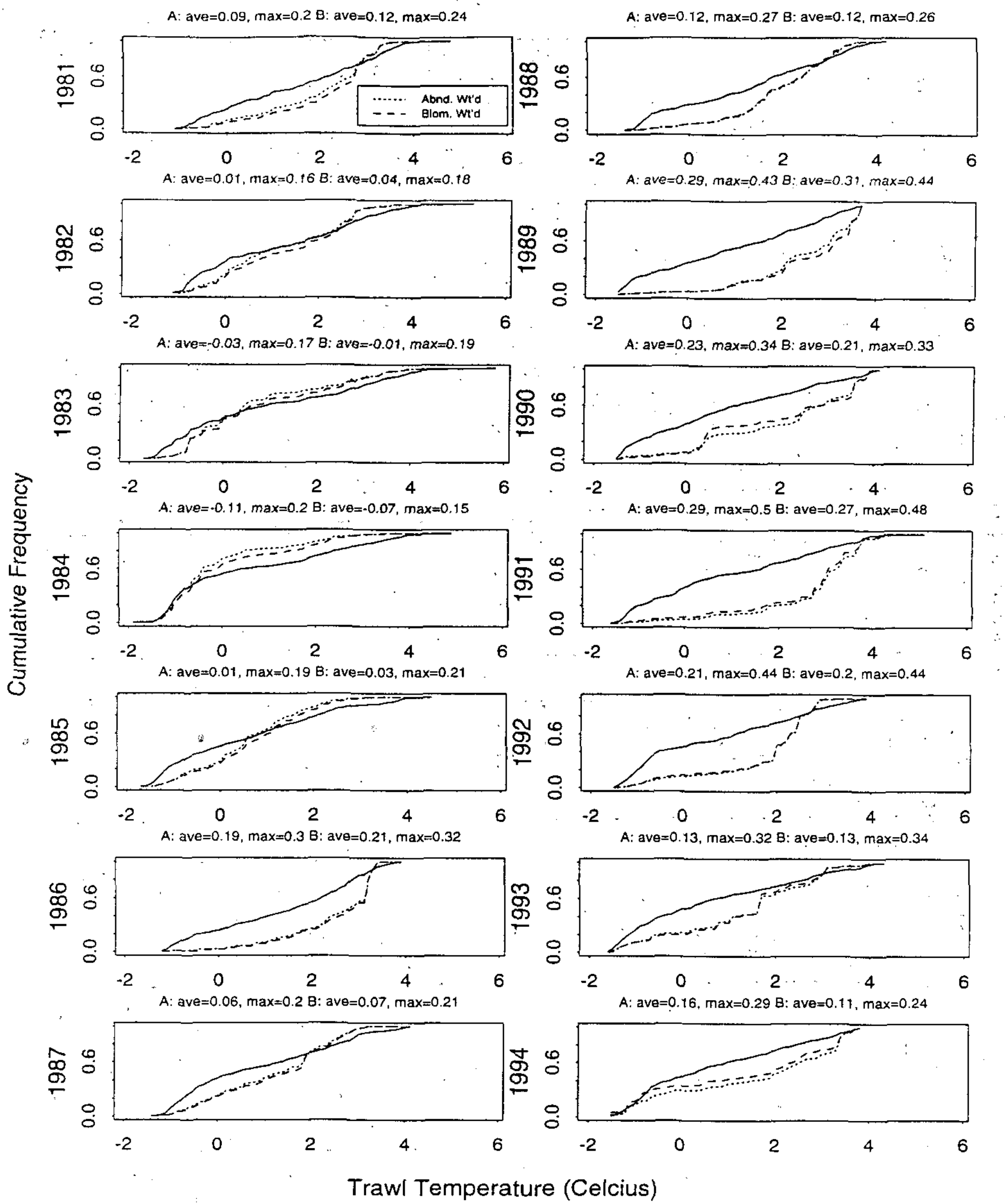

Figure 2a. Cod abundance (numbers per tow) and biomass (tow weights) weighted and unweighted bottom temperature cumulative frequency distributions for the 2J3KL trawl fall survey. The unweighted CDF is plotted as a solid line, and the weighted CDFs are plotted as broken lines. The average difference in a weighted and unweighted CDF is denoted by **ave**, while the maximum absolute difference is denoted by **max**.

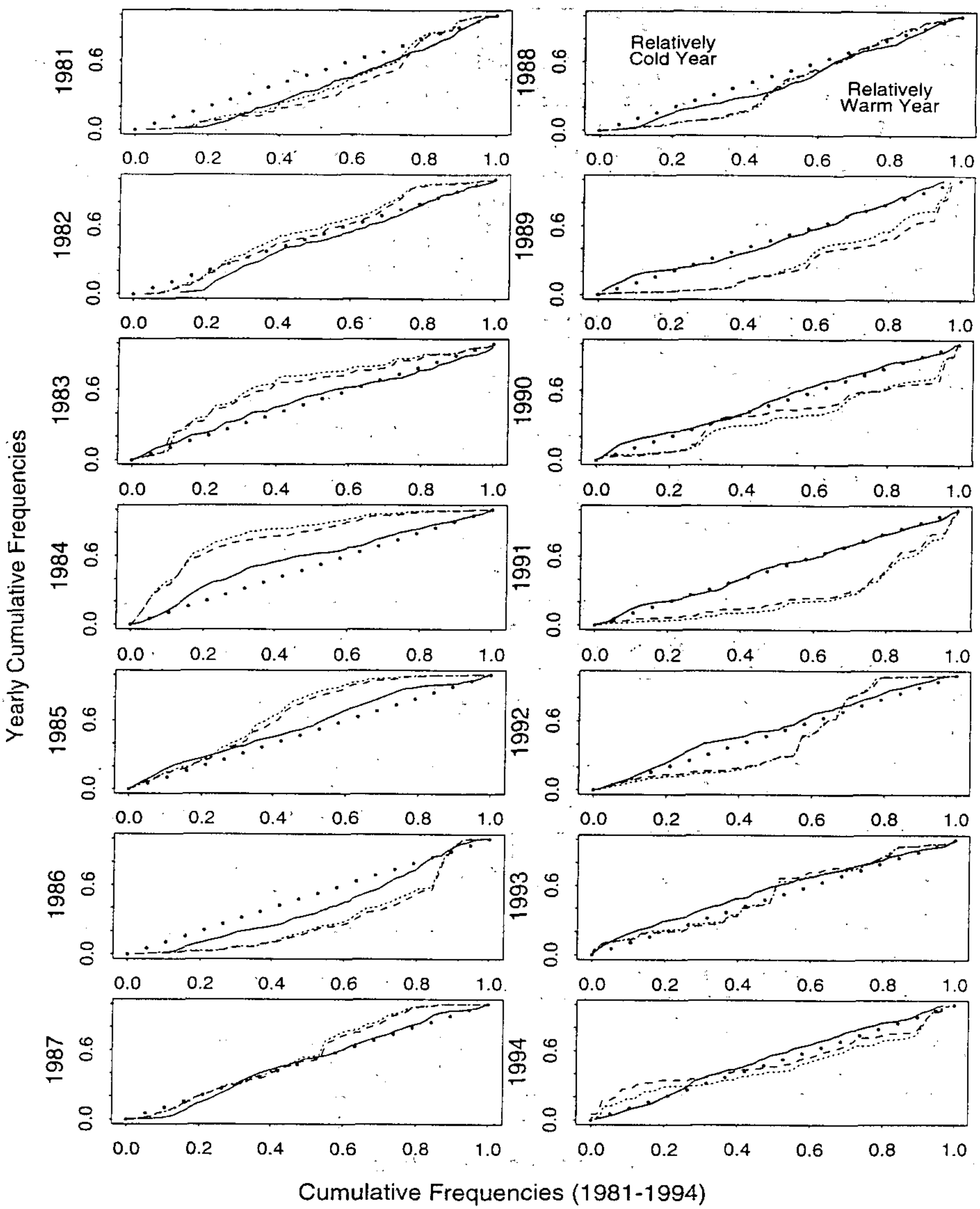

Figure 2b. Yearly weighted and unweighted bottom temperature cumulative frequency distributions versus the corresponding 1981-1994 combined distributions for the 2J3KL trawl fall survey. The points denote a 1:1 relationship.

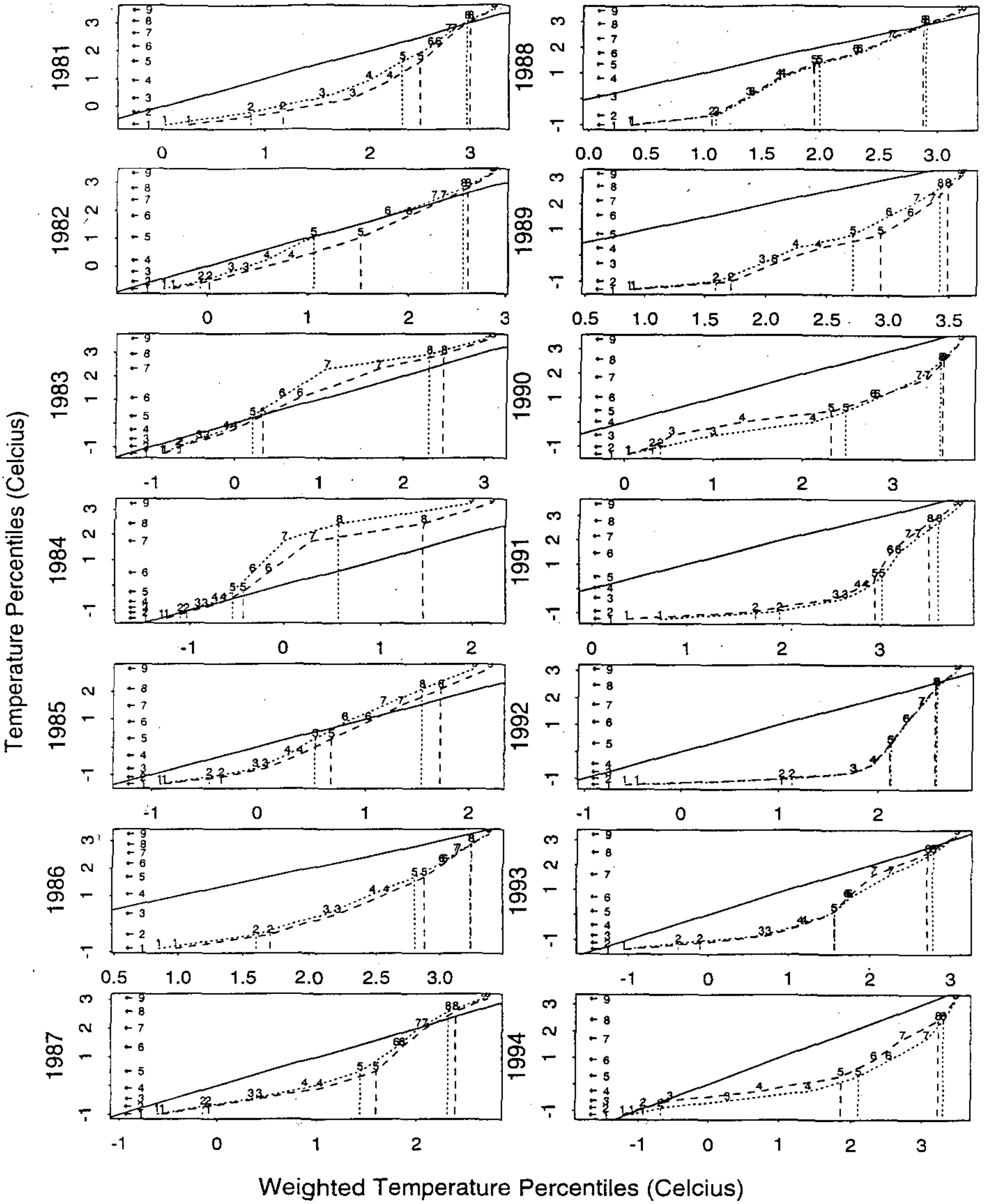

Figure 2c. Cod abundance and biomass weighted bottom temperature percentiles versus unweighted bottom temperature percentiles for the 2J3KL trawl fall survey. The solid line denotes a 1:1 relationship. The $(x \times 10)$th percentiles, $x = 1, ..., 9$ are plotted as x's. Vertical lines are plotted for the 20th, 50th, and 80th weighted percentiles. The unweighted temperature percentiles are plotted as $\leftarrow$'s.

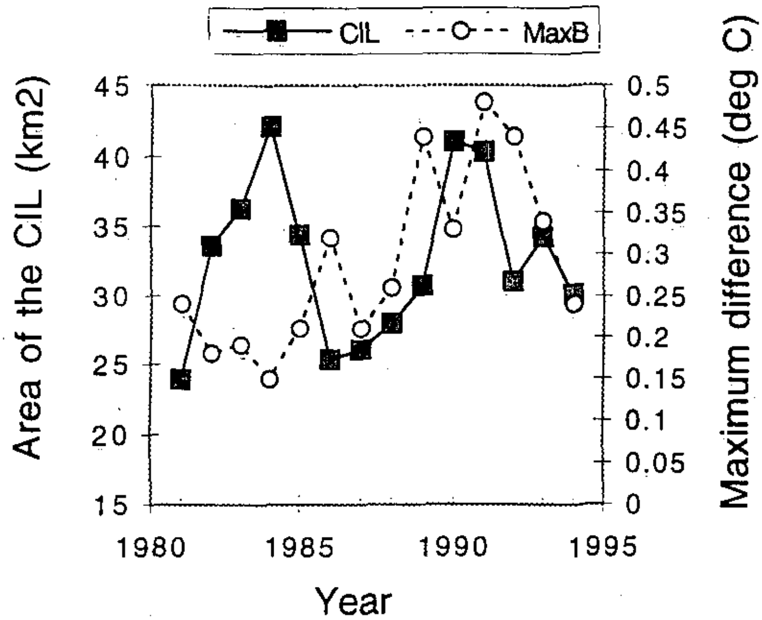

Fig. 2d. Area of the CIL (average for the Seal Island, Bonavista and Flemish Cap transects, from Colbourne) and the difference between weighted (biomass) and unweighted CDFs for 2J3KL fall surveys.

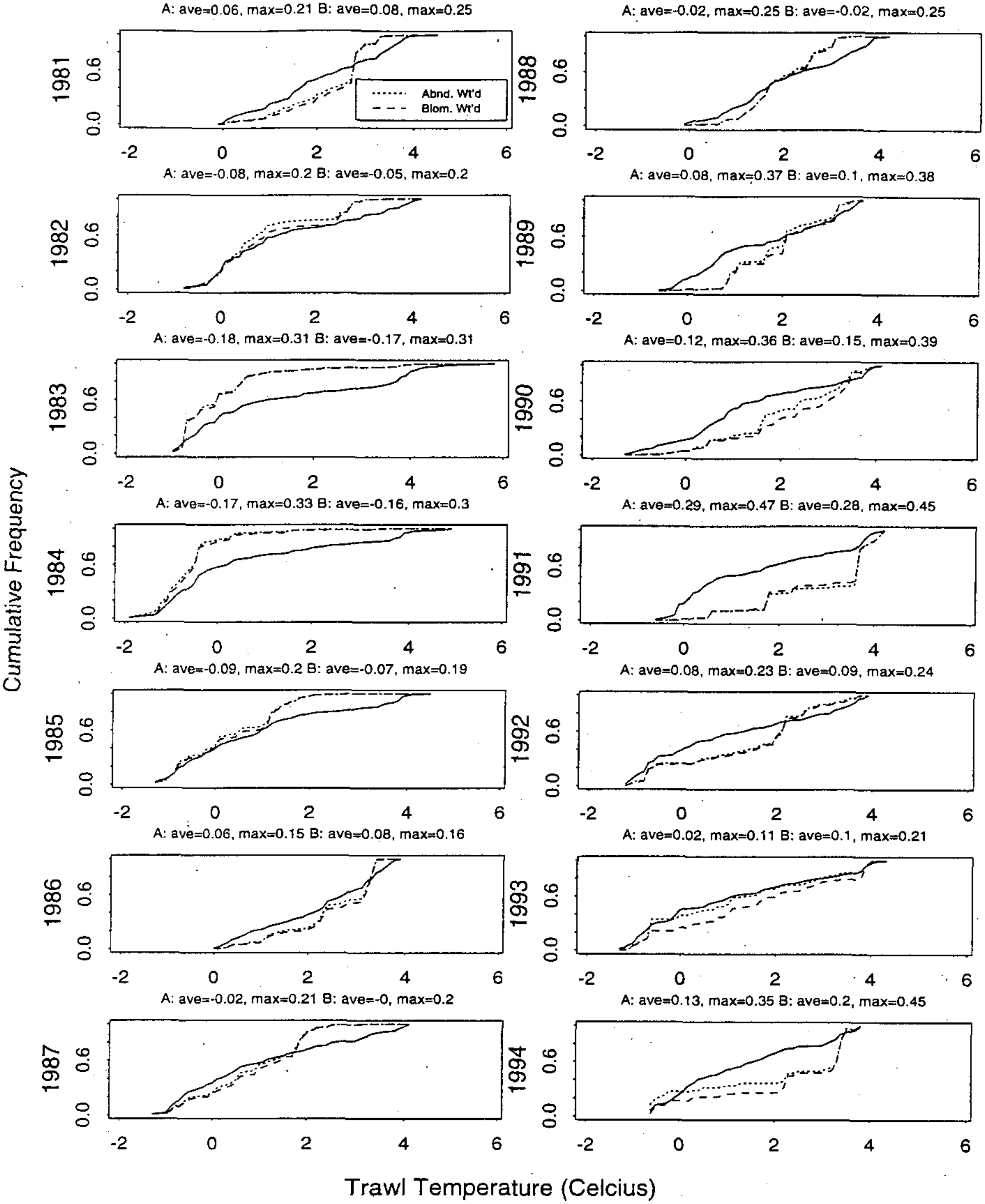

Figure 3a. Cod abundance (numbers per tow) and biomass (tow weights) weighted and unweighted bottom temperature cumulative frequency distributions for the 2J trawl fall survey. The unweighted CDF is plotted as a solid line, and the weighted CDFs are plotted as broken lines. The average difference in a weighted and unweighted CDF is denoted by **ave**, while the maximum absolute difference is denoted by **max**.

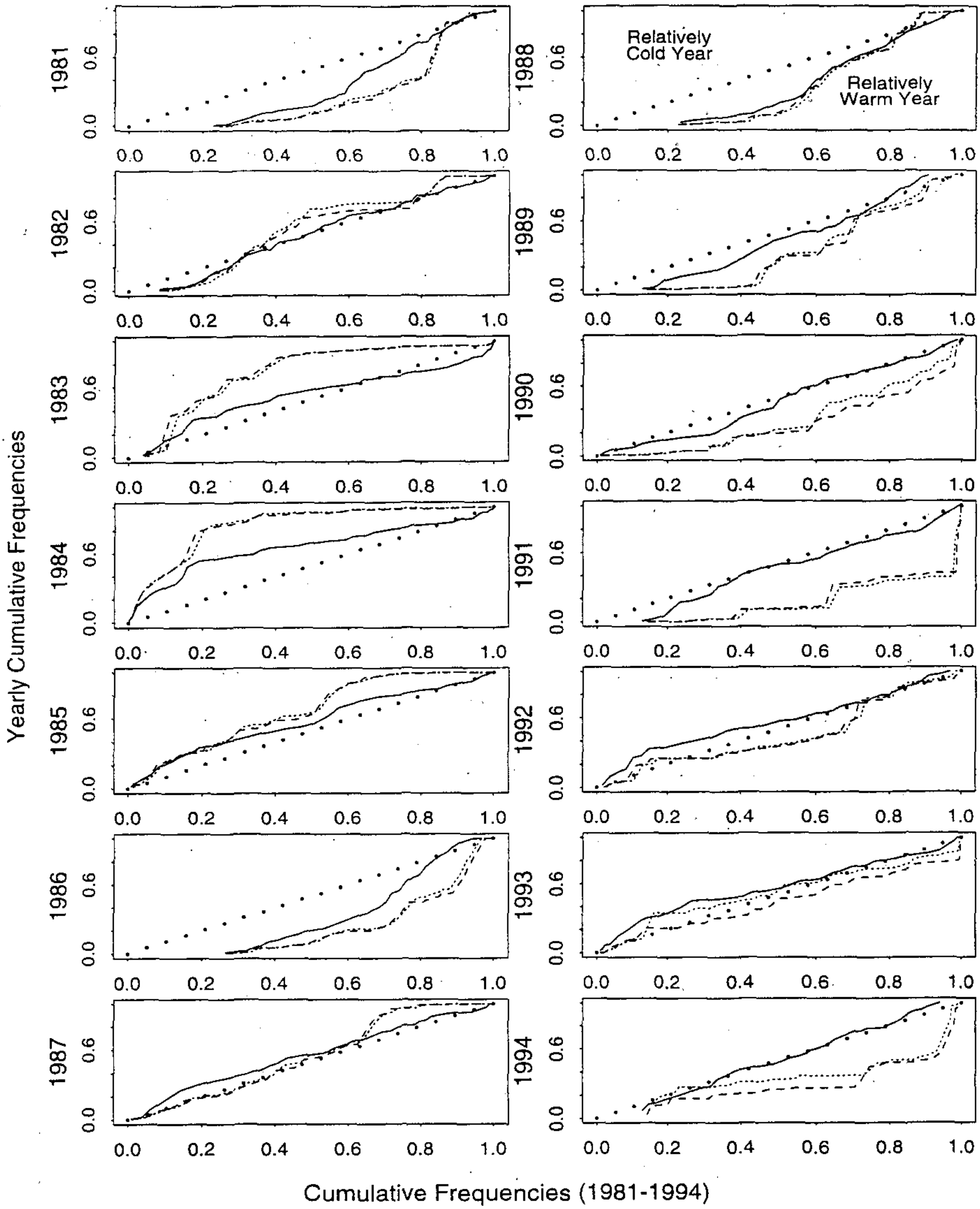

Figure 3b. Yearly weighted and unweighted bottom temperature cumulative frequency distributions versus the corresponding 1981-1994 combined distributions for the 2J trawl fall survey. The points denote a 1:1 relationship.

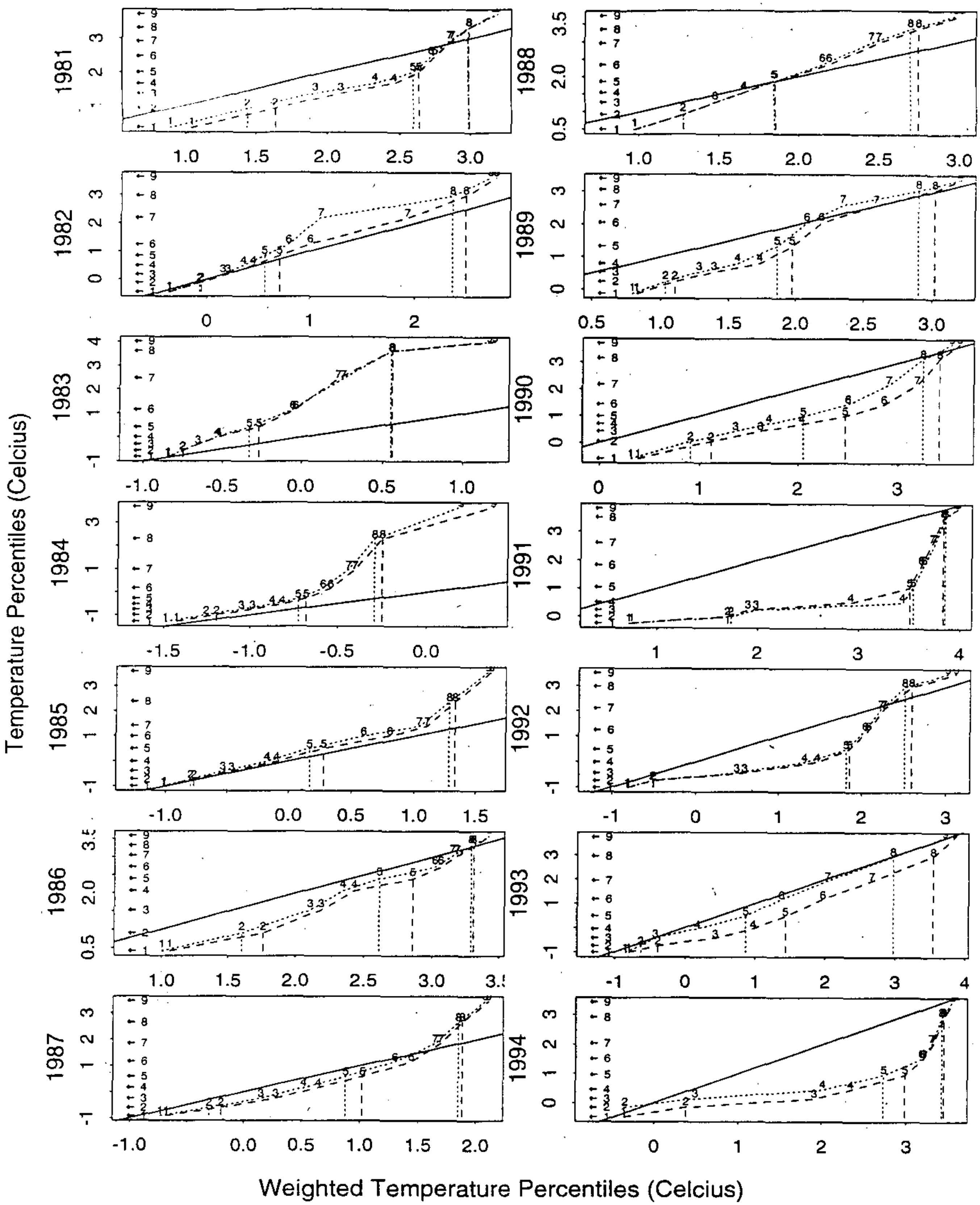

Figure 3c. Cod abundance and biomass weighted bottom temperature percentiles versus unweighted bottom temperature percentiles for the 2J trawl fall survey. The solid line denotes a 1:1 relationship. The $(x \times 10)$th percentiles, $x = 1, \ldots, 9$ are plotted as x's. Vertical lines are plotted for the 20th, 50th, and 80th weighted percentiles. The unweighted temperature percentiles are plotted as $\leftarrow$'s.

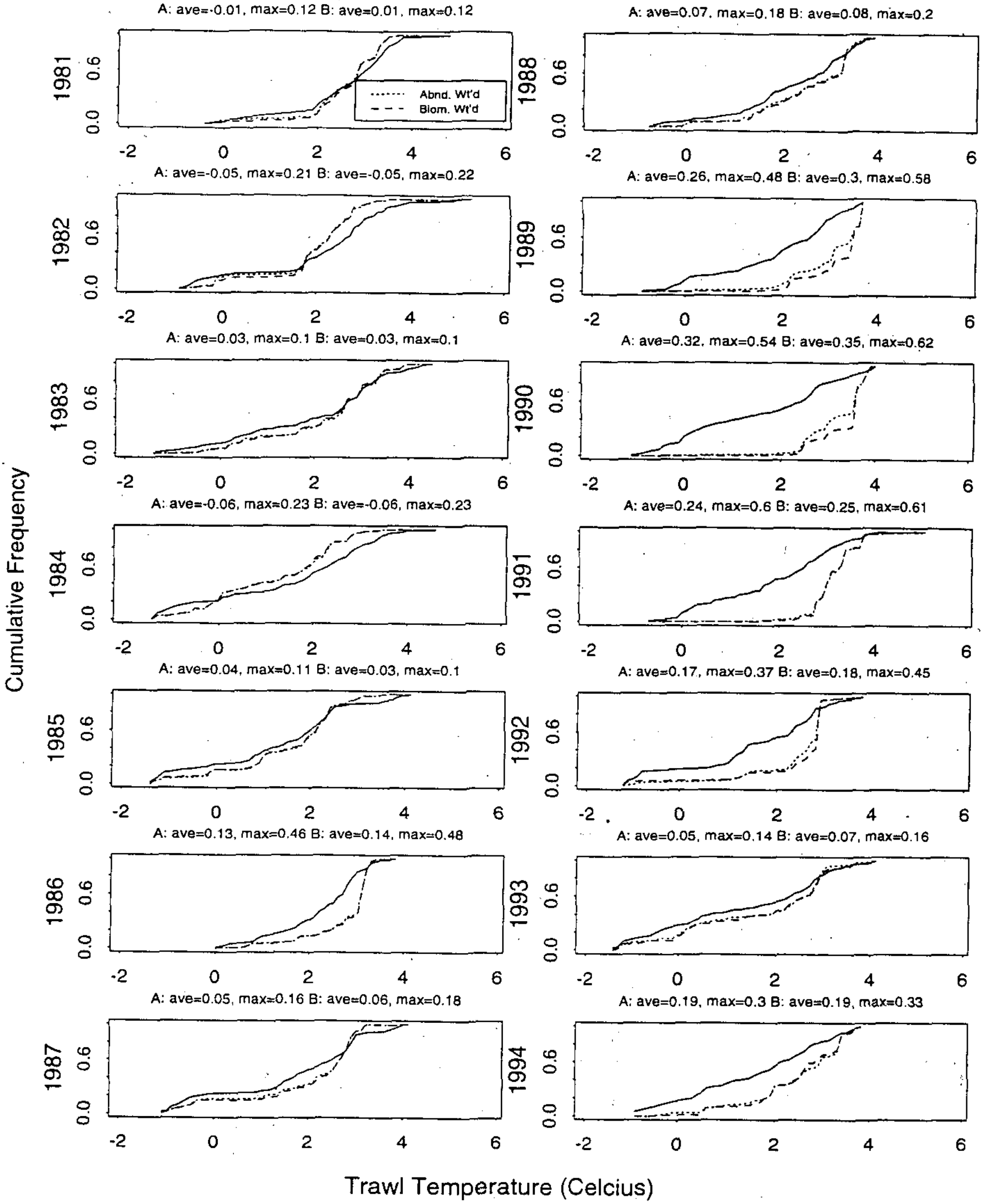

Figure 4a. Cod abundance (numbers per tow) and biomass (tow weights) weighted and unweighted bottom temperature cumulative frequency distributions for the 3K trawl fall survey. The unweighted CDF is plotted as a solid line, and the weighted CDFs are plotted as broken lines. The average difference in a weighted and unweighted CDF is denoted by **ave**, while the maximum absolute difference is denoted by **max**.

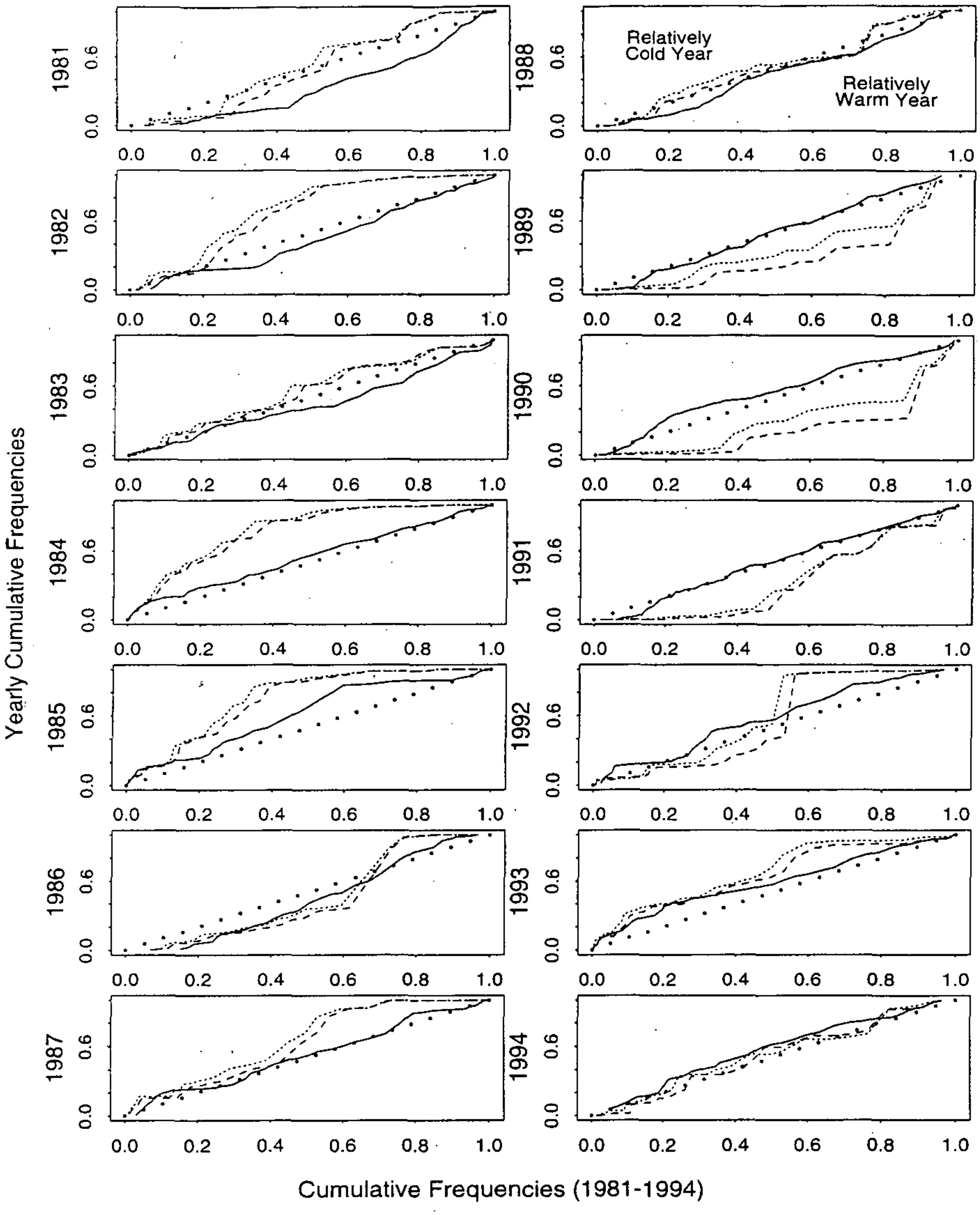

Figure 4b. Yearly weighted and unweighted bottom temperature cumulative frequency distributions versus the corresponding 1981-1994 combined distributions for the 3K trawl fall survey. The points denote a 1:1 relationship.

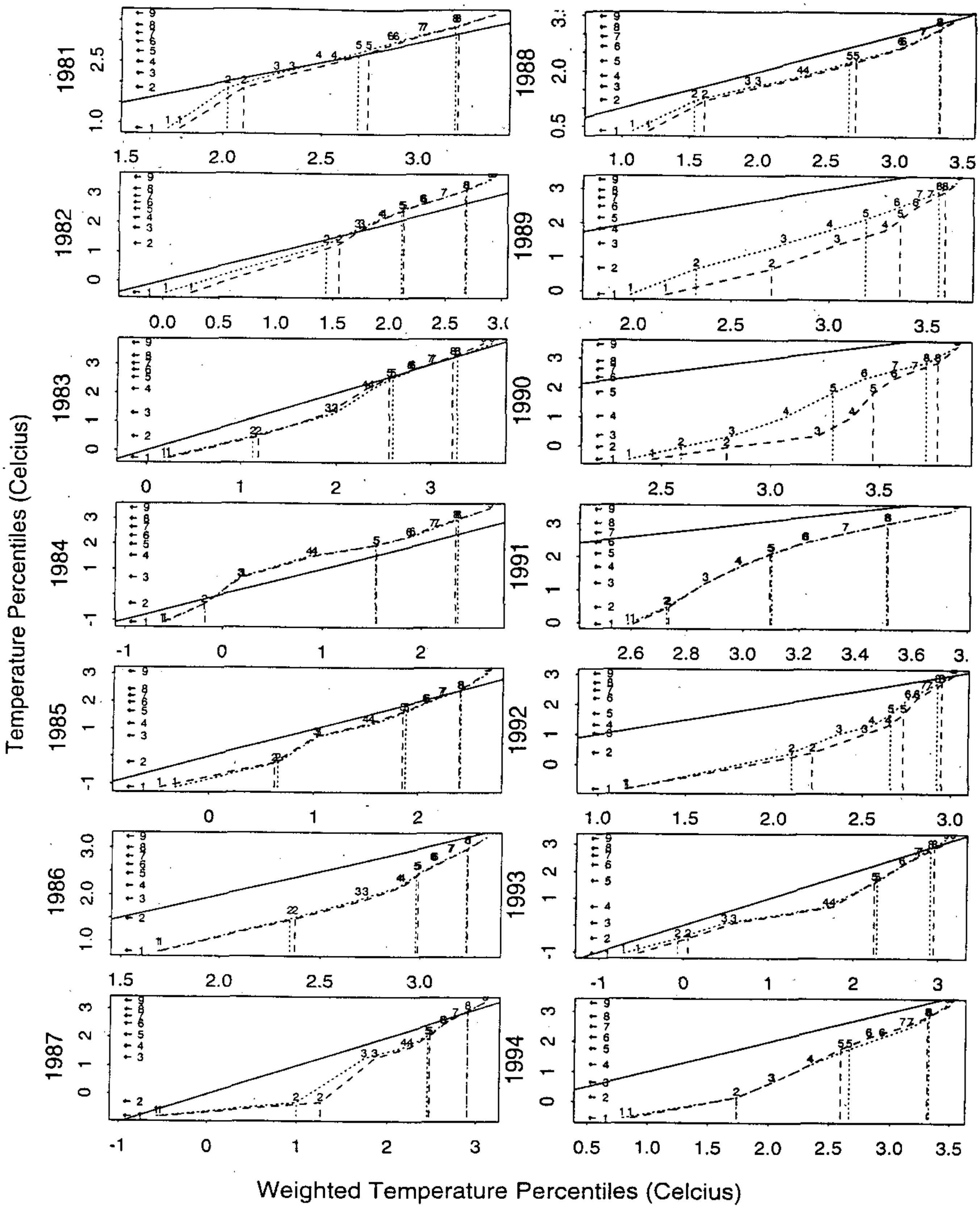

Figure 4c. Cod abundance and biomass weighted bottom temperature percentiles versus unweighted bottom temperature percentiles for the 3K trawl fall survey. The solid line denotes a 1:1 relationship. The $(x \times 10)$th percentiles, $x = 1, \ldots, 9$ are plotted as x's. Vertical lines are plotted for the 20th, 50th, and 80th weighted percentiles. The unweighted temperature percentiles are plotted as $\leftarrow$'s.

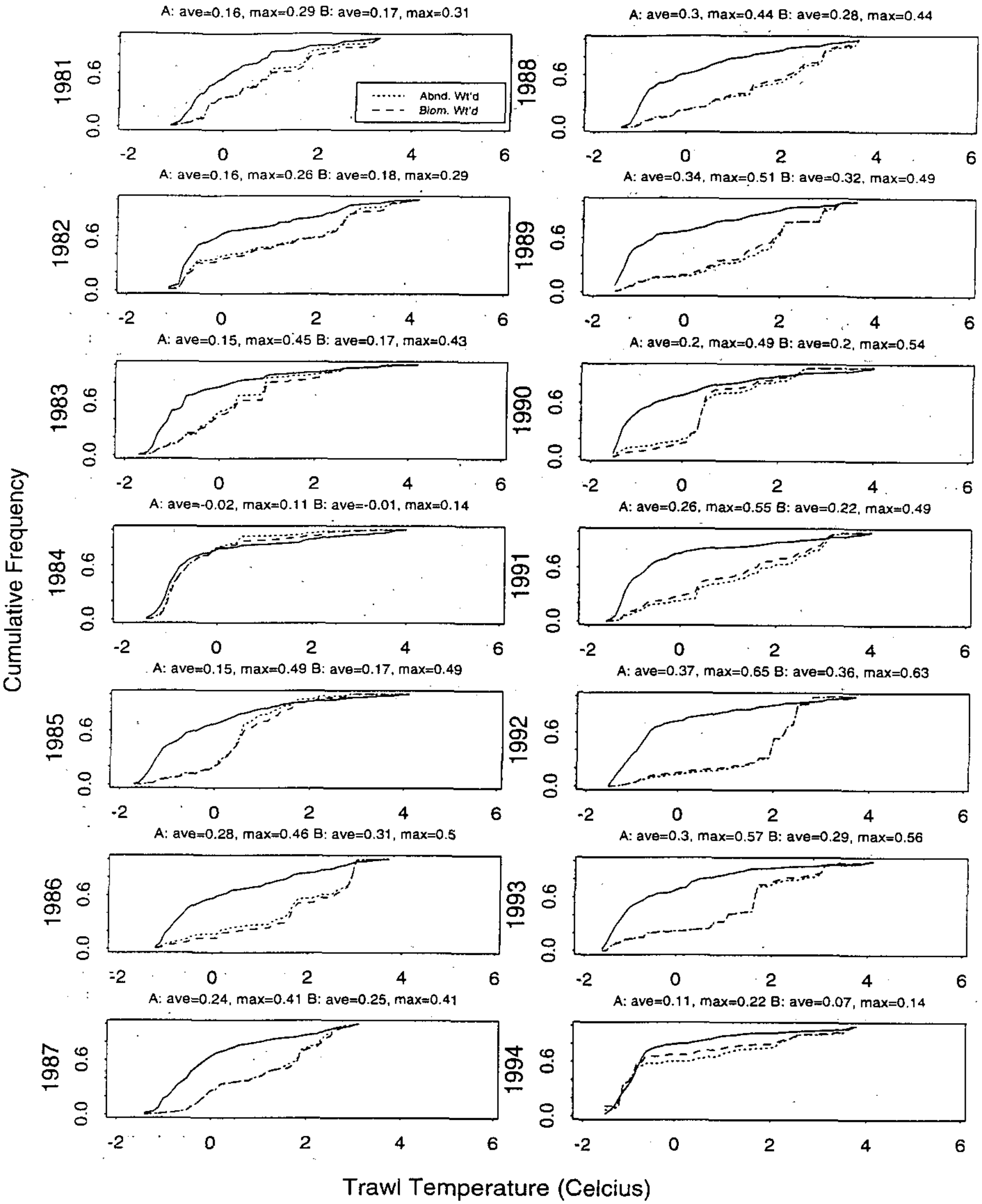

Figure 5a. Cod abundance (numbers per tow) and biomass (tow weights) weighted and unweighted bottom temperature cumulative frequency distributions for the 3L trawl fall survey. The unweighted CDF is plotted as a solid line, and the weighted CDFs are plotted as broken lines. The average difference in a weighted and unweighted CDF is denoted by **ave**, while the maximum absolute difference is denoted by **max**.

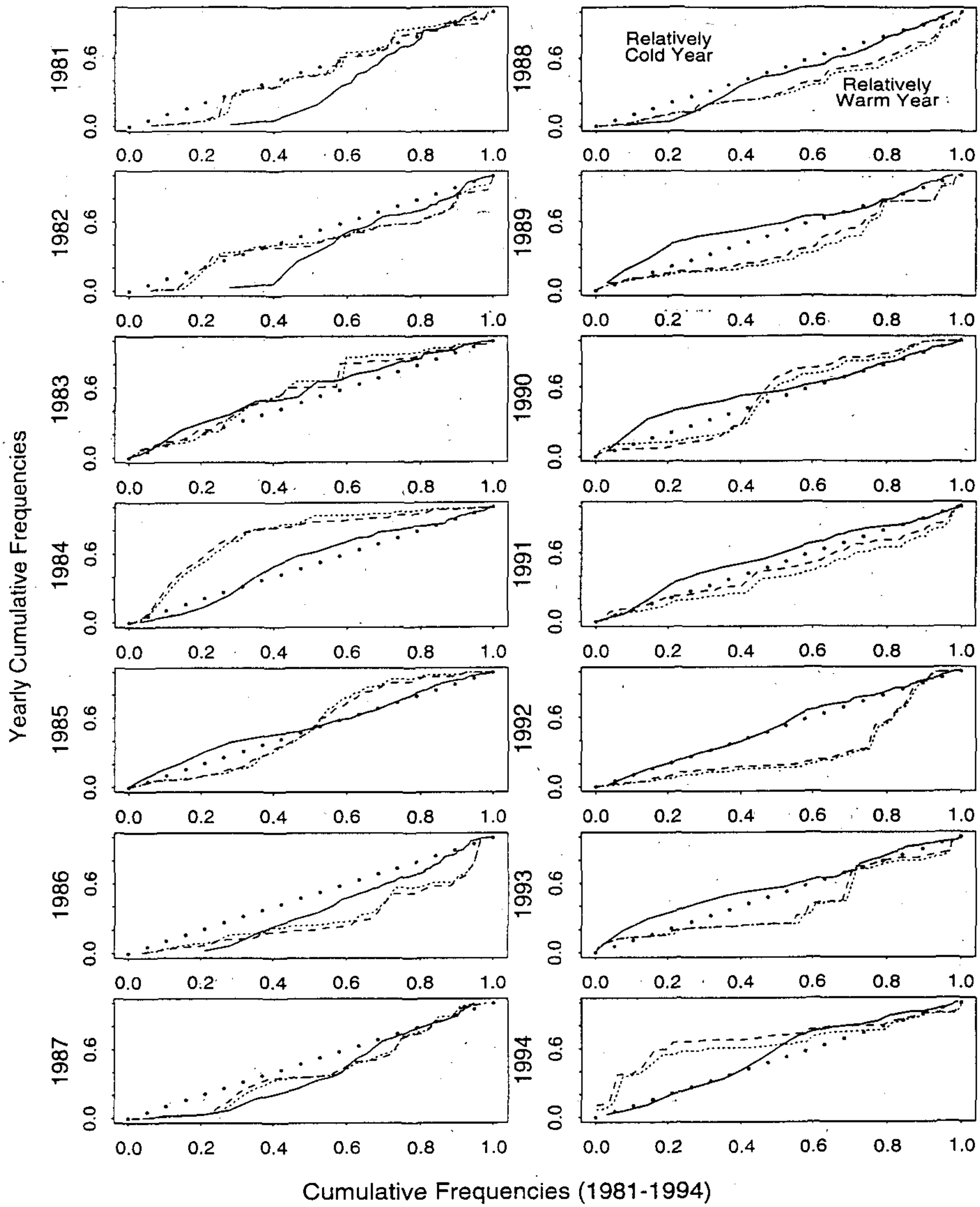

Figure 5b. Yearly weighted and unweighted bottom temperature cumulative frequency distributions versus the corresponding 1981-1994 combined distributions for the 3L trawl fall survey. The points denote a 1:1 relationship.

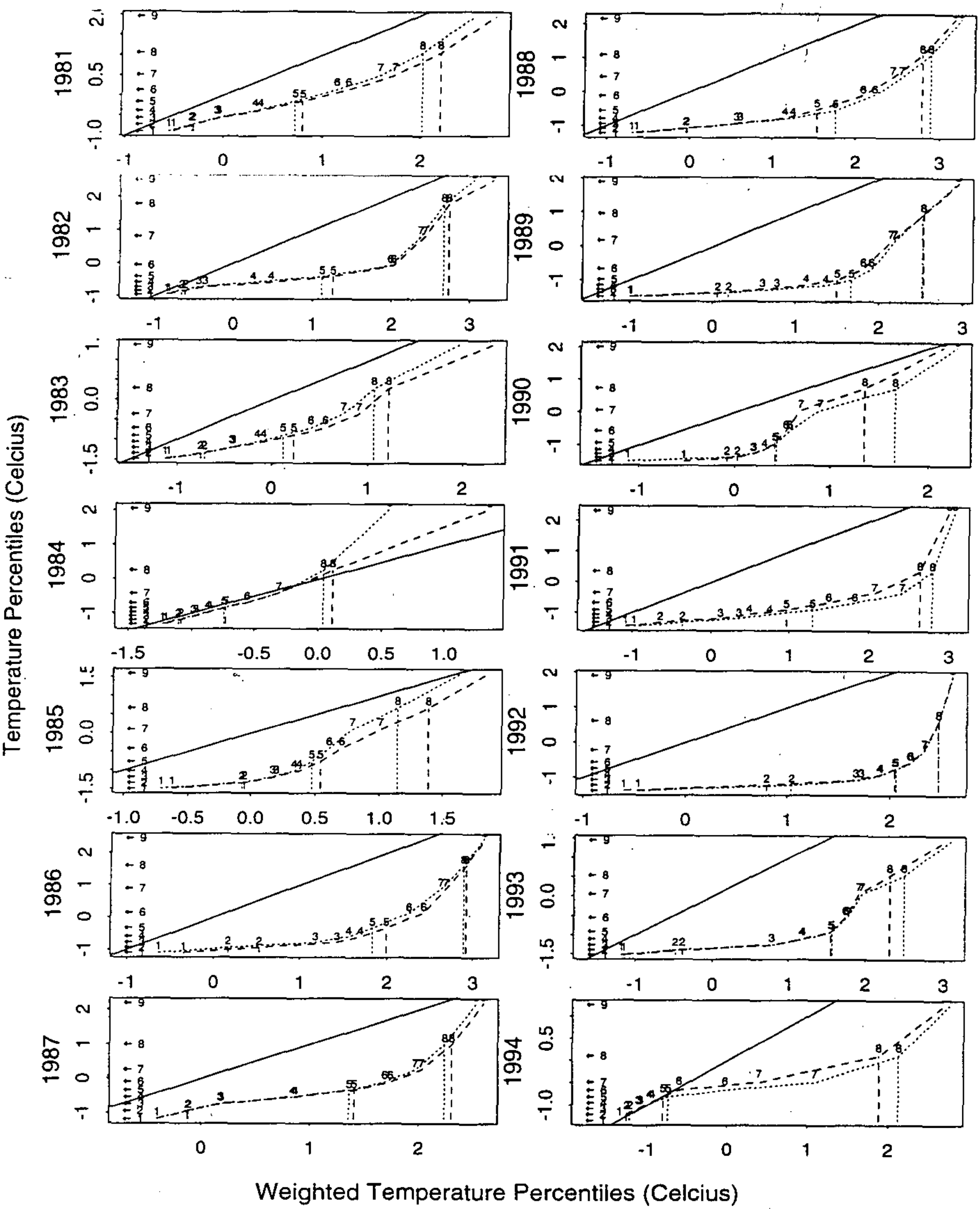

Figure 5c. Cod abundance and biomass weighted bottom temperature percentiles versus unweighted bottom temperature percentiles for the 3L trawl fall survey. The solid line denotes a 1:1 relationship. The $(x \times 10)$th percentiles, $x = 1, ..., 9$ are plotted as x's. Vertical lines are plotted for the 20th, 50th, and 80th weighted percentiles. The unweighted temperature percentiles are plotted as $\leftarrow$'s.