Deep-Sea Research, Vol. 31, No. 10, pp. 1259 to 1264, 1984.
Printed in Great Britain.

0198-0149/84 $3.00 + 0.00

NOTE

Pelagic *Sargassum*: has its biomass changed in the last 50 years?

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(*Received 22 August 1983; accepted 9 December 1983*)

Abstract—The quantity and distribution of *Sargassum* in the Sargasso Sea, as estimated by various investigators, is reviewed. There has apparently been no significant change in the biomass of *Sargassum* from 1933 to 1981, except for an area northeast of the Antilles (20 to 25°N, 62 to 68°W), where measurements made in November 1977 and November 1980 were about 0.1% of values measured in February and March 1933. Because of the lack of change in the Bermuda, Bahamas, or Gulf Stream regions, the effect does not appear to be due to pollution or to broad climatic changes; it is most likely due to a seasonal change in *Sargassum* abundance or to a long-term shift of currents defining the southwestern boundary of the Sargasso Sea.

STONER (1983) carried out a series of neuston tows in the western Sargasso Sea from 1977 to 1981 and compared his results with those obtained by PARR (1939) in 1933 to 1935. His conclusion was that there had been a major decrease (a factor of 10) in *Sargassum* biomass during the intervening years. That conclusion depended on a statistical analysis that did not consider geographic variation in biomass within the Sargasso Sea. In addition, the analysis was based on simple arithmetic means of biomass concentrations, which do not weight the data appropriately when neuston tows are of different length. In this revised analysis we have taken account of the above factors and have localized the observations that caused the major difference reported by STONER (1983).

Consider first the Bermuda region, or northwestern Sargasso Sea (30 to 40°N, 60 to 70°W), where data from Morris's time series (BUTLER *et al.*, 1973; BUTLER and MORRIS, 1974; BUTLER *et al.*, 1983) can be included in the comparison with PARR (1939) and STONER (1983) (Fig. 1). The heights of the histogram bars are proportional to the length of tow used to take the sample, and the horizontal axis is the wet weight of *Sargassum* per unit area of ocean as reported for each neuston tow. Morris and Stoner used relatively short tows, about 1 km, whereas Parr towed his net while the *Atlantis* steamed between stations; typical tows were 30 to 40 km and occasionally Parr's tows approached 200 km in length.

The approximately log-normal distribution of the data is evident in Fig. 1, and it is clear that a simple arithmetic mean does not represent the best measure of central tendency for such a distribution. However, the geometric mean cannot always be calculated because of

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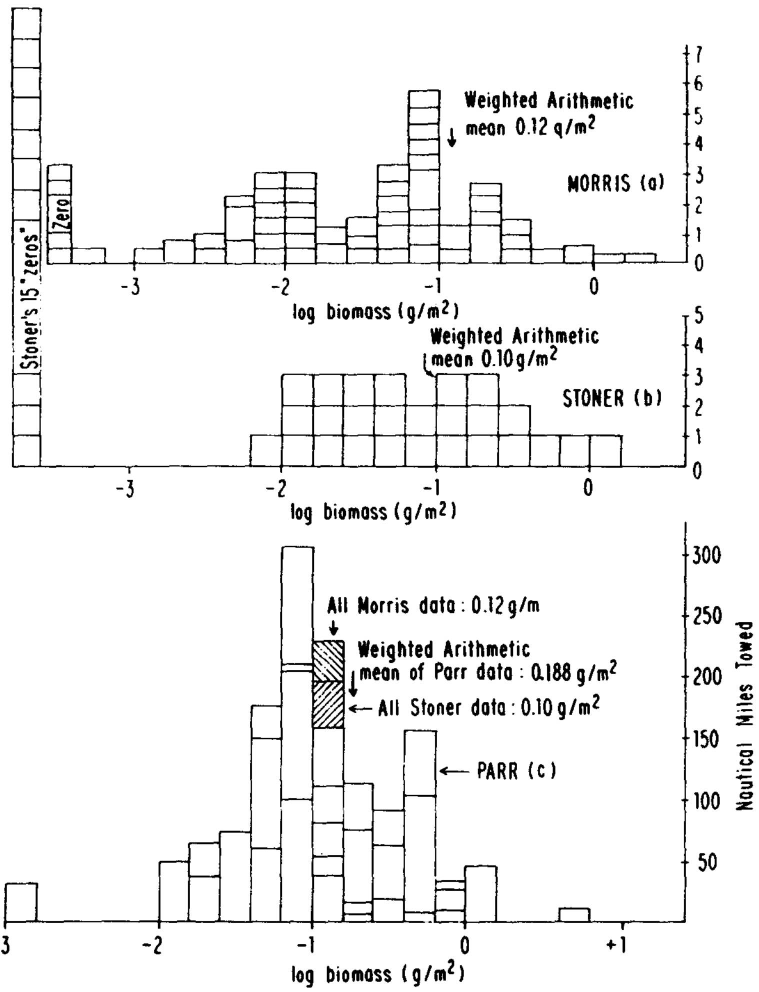

Fig. 1. Comparison of Morris (a), Stoner (b), and Parr (c) data for 30 to 40°N, 60 to 70°W (northwest Sargasso Sea).

'zero' observations of uncertain magnitude, which have considerable influence on the geometric mean (Morris *et al.*, 1975).

The most appropriate measure of total biomass in the area surveyed is the total weight of *Sargassum* collected in all tows, divided by the total area of ocean surface skimmed. In Stoner's study, tows were all approximately the same length (1 nmi or 1.85 km), and so this weighted mean is identical with the arithmetic mean of the *Sargassum* density at his various stations. On the other hand, Parr and Morris both made tows of variable length, and the variation in Parr's length of tow (as mentioned above and in Fig. 1) was very large.

The weighted means for Morris's and Stoner's data are 0.12 and 0.10 g m^{-2} respectively. In Fig. 1c the total of Morris's and Stoner's data have been plotted as if each were one of Parr's long tows. Although the values are lower than the weighted mean of Parr's data (0.188 g m^{-2}), the central position of the summary values in Parr's distribution shows clearly that there is no significant difference between the three data sets. Parr's and Stoner's data were compared quantitatively by a t-test, which used the weighted means, calculated as described above, and mean-square deviations from these means based on the logarithmic distribution.* If zeros were set equal to 0.0001 g m^{-2} the procedure gave $t = 0.76$ with 73 d.f., corresponding to $P = 0.46$—a 46% probability that the two means are the same. If the zeros were omitted from the data set, $t = 0.24$, and $P \gg 0.5$ for 56 d.f. Therefore there has probably been no significant change in biomass of *Sargassum* in the Bermuda region since 1933.

Similar conclusions can be drawn from comparisons in the Gulf Stream and Bahamas regions (Fig. 2). Howard and Menzies (1969) estimated the amount of *Sargassum* by visual observations during 1966 from the bridge of the RV. *Eastward* and calculated a standing crop of 0.52 g m^{-2} for the 'Gulf Stream' and 0.24 g m^{-2} for the 'Sargasso Sea'. Actually, all the observations were in the region 31 to 35°N, 72 to 79°W. For comparison, a region bounded by 30 to 40°N, 70 to 80°W was used. In this region the weighted mean of Stoner's data was higher than Parr's: 0.54 vs 0.165 g m^{-2}, but this is not a significant increase in the Gulf Stream region from 1933 to 1981. (With zeros set to 0.0001 g m^{-2}, $t = 0.88$, and $P = 0.40$ for 19 d.f.)

The Bahamas region (20 to 30°N, 70 to 80°W) likewise shows no significant difference between Parr's and Stoner's observations ($t = 0.55$, and $P = 0.59$ for 42 d.f.). Weighted arithmetic means were 0.55 and 0.33 g m^{-2}, respectively, and the total of Stoner's data fell in the middle of Parr's distribution.

In contrast, there is a highly significant difference between Parr's and Stoner's results in the southwestern Sargasso Sea (20 to 30°N, 57 to 70°W, Fig. 3). The weighted mean for Parr's 1933 to 1935 survey is 1.08 g m^{-2}, and for Stoner's 1977 to 1981 survey the weighted mean is 0.055 g m^{-2}, a factor of 20 less. If all Stoner's data are summed and treated as a single tow from Parr's set, they fall at the lowest end of Parr's distribution (Fig. 3) and the chance that the means are the same is <0.001% ($t = 4.6$, $P = 0.00001$ for 82 d.f.).

Thus the only significant differences in *Sargassum* biomass appear to be in the southwestern Sargasso Sea. Agreement among the four studies in other parts of the western North Atlantic appears to be good and implies that most of the obvious causes of sampling bias were not a major factor (e.g., Stoner used shorter tows, finer net mesh, and slower towing speed than did Parr). Furthermore, effects of pelagic tar, nutrient depletion, or climatic variation (Parr and others proposed that the northern boundary of the Sargasso Sea is defined by death of the algae in winter) all might be expected to be greater in the more highly stressed pelagic community of the northern Sargasso Sea, but in that region the effects appear to be small compared to variability in sampling (Fig. 1).

Although most of Parr's stations were further west (65 to 70°W) than Stoner's (58 to 61°W), there is some overlap (Fig. 4). Near 25°N, 67°W, Stoner obtained *Sargassum*

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* If $\bar{x}$ is the logarithm of the total biomass divided by the total area sampled, then

$$t = \frac{\bar{x}_1 - \bar{x}_2}{(S_1^2/N_1 + S_2^2/N_2)^{1/2}}.$$

For each study consisting of N tows,

$$\frac{S^2}{N} = \frac{\Sigma(x_i - \bar{x})^2}{N(N-1)},$$

where x_i is the logarithm of the biomass per unit area for each tow.

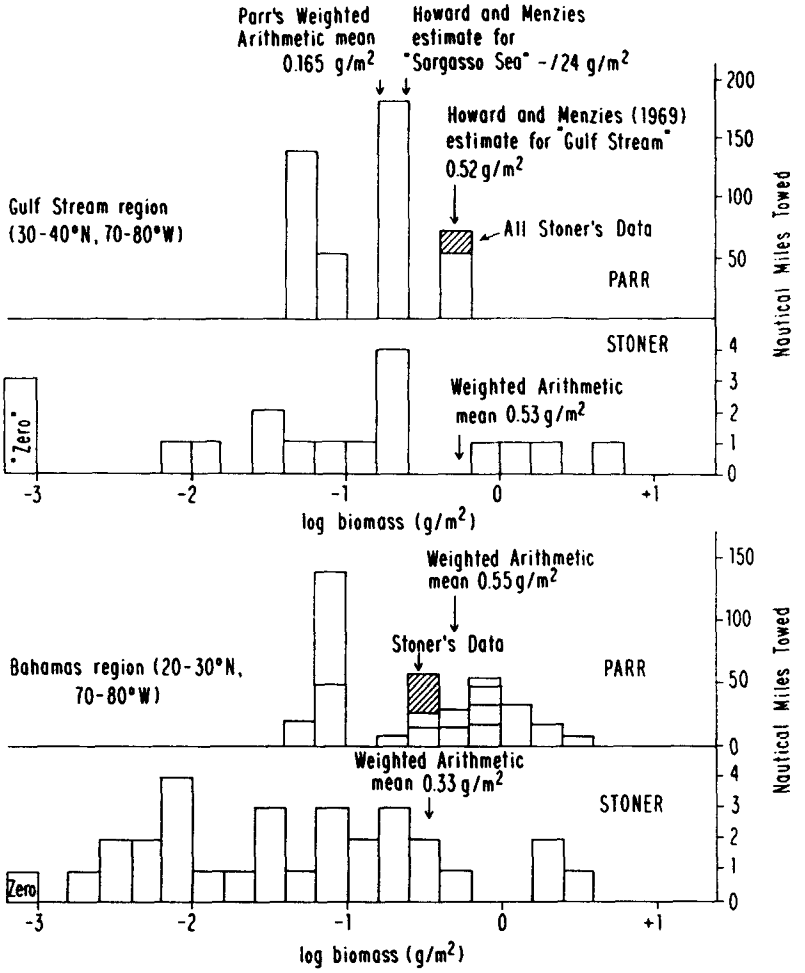

Fig. 2. Comparison of data for the Gulf Stream and Bahamas regions.

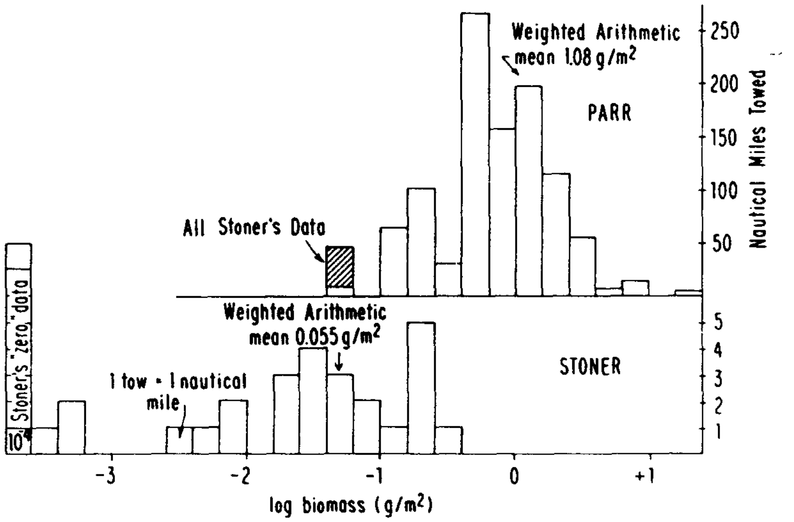

Fig. 3. Comparison of Parr's and Stoner's data for the southwestern Sargasso Sea (20 to 30°N, 57 to 70°W).

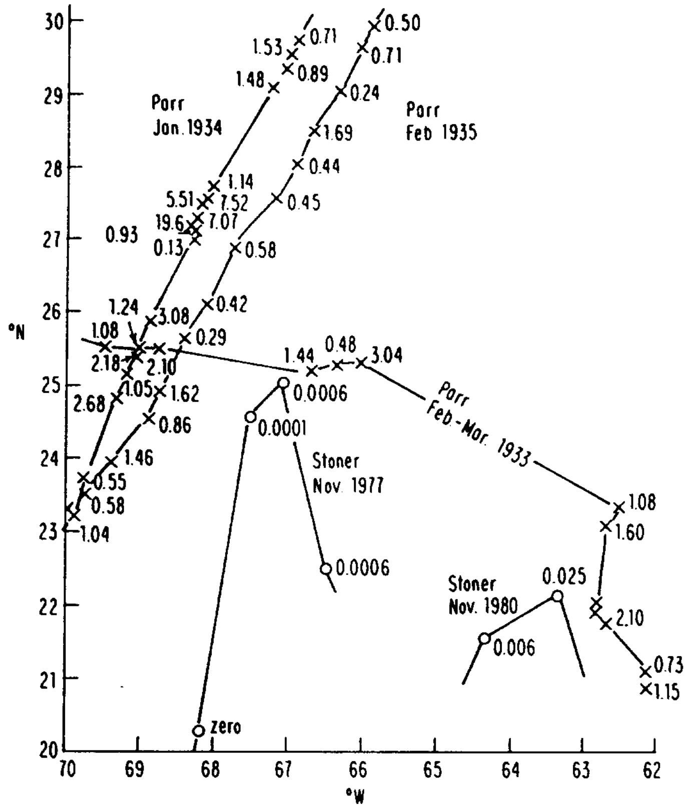

Fig. 4. Comparison of Parr's and Stoner's cruise tracks. Additional tows were made by Stoner east of 61°W (Butler *et al.*, 1983).

biomass <0.001 g m^{-2} in a place where Parr had found 0.48 to 3.04 g m^{-2}. The difference far exceeds any year-to-year variability observed by either investigator.

At least two explanations may be invoked for the large differences observed in the southwestern Sargasso Sea:

(1) Observations were made at different times of year. Parr's collections were in January to March and Stoner's were in October and November. It is not possible to say, without further field work, whether there are large seasonal shifts in *Sargassum* abundance in the region, but Morris's time-series from Bermuda (Butler *et al.*, 1983) suggests the possibility.

(2) Long-term shifts in currents defining the southwestern boundary of the Sargasso Sea may have occurred. For example, McDowell and Rossby (1978) described a mesoscale eddy at 24°N, 70°W that originated near the Mediterranean outflow in the eastern North Atlantic. By analogy, the area in which surface convergences were most intense might easily shift a few hundred kilometers. However, the physical processes that control the distribution and abundance of *Sargassum* remain poorly understood.

Acknowledgements—This work was supported by the Sea Education Association (AWS) and a grant from the Zemurray Foundation (to JNB). Contribution No. 976 from the Bermuda Biological Station for Research.

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