The Variation in the Catch of Plankton Nets in a System of Estuaries[1]

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ABSTRACT

In a study of variability in copepod catch during a tidal cycle at 17 stations in the St. Andrew Bay System of Florida, the coefficient of variation (c. v.) for the total copepod count of a single oblique tow was found to be 43%. The c.v. for counts of three different species ranged between 51–56%. The least variation occurred in the index of community diversity (c.v. 17%). Tests of catch variance against estimates of error arising from collecting and counting the copepods indicate that, at most stations, variation in catch resulted from irregular distribution of the plankton in the water. Correlation coefficients, calculated by using count variance and hydrographic data recorded for each station, suggest that tow variability may be greatly influenced by vertical stability of the water. Means of reducing tow variability were considered and it was concluded that several tows spaced over a portion of a tidal cycle are more effective in estimating the average biological characteristics at a station in an estuary than a tow that filters a larger amount of water at a single sampling.

Introduction. Information has been published on tow-net catch variability in both the open sea (Winsor and Clarke, 1940) and in freshwater lakes (Ricker, 1938) where hydrographic changes resulting from tidal movement are disregarded. Data on net-catch variability in estuaries, however, where water at any particular point may vary tremendously in its physical and biological properties over a tidal cycle, have been difficult to locate. This paper treats the variability of the copepod population over a portion of a diurnal tidal cycle at stations established throughout the St. Andrew Bay System of Florida (Fig. 1). Considered here are factors that may influence this variability as well as possible means of reducing tow variability.

1 This research was supported by the Office of Naval Research, Biology Branch, Contract Nonr 988(06). I would like to acknowledge the assistance of Dr. R. G. Cornell of the Department of Statistics, Florida State University, in the statistical aspects of this paper.

2 Florida State University Oceanographic Institute Contribution No. 192.

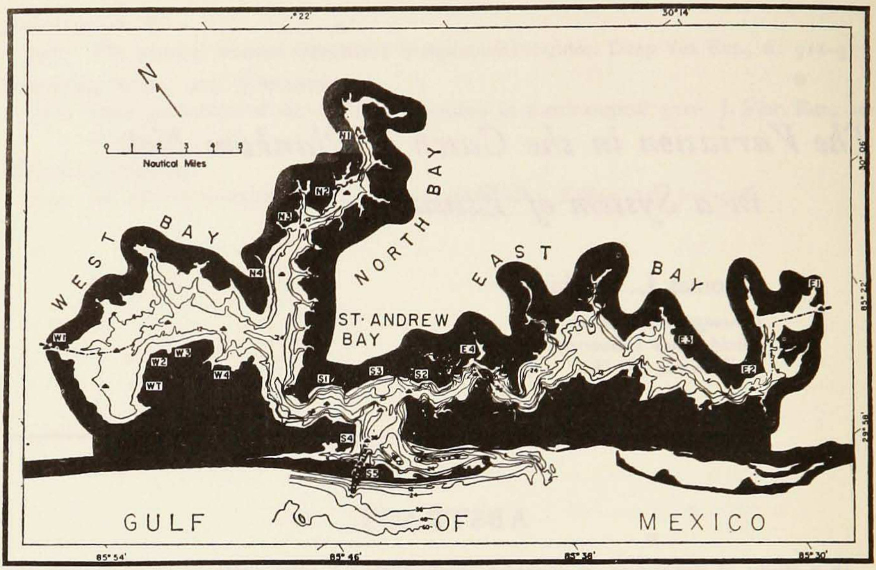

Figure 1. St. Andrew Bay system, Gulf coast of northern Florida, between 30–31°N and 85–86°W. Depth contour in feet.

Methods. Hydrographic measurements recorded for each station were: surface and bottom salinity, current velocity and direction, and temperature. Salinities were calculated from chlorinity using the Knudsen method, and current velocities were estimated with Pritchard current crosses. Vertical and horizontal temperature variations were small and were considered negligible.

Copepods were captured in five-minute oblique tows with calibrated Clarke-Bumpus samplers equipped with No. 10 nylon nets. Each haul was accomplished by first determining the depth (D) at a particular station, then towing parallel to the long axis of the channel at the surface, $^1/_4$D, $^1/_2$D, $^3/_4$D, and just above the bottom for one minute at each level. Each station was sampled four to six times during the daylight hours of a diurnal tidal cycle, with samples generally being collected at two-hour intervals.

Counts were made of each species of copepod occurring in aliquots, with counts of copepodid and adult stages being combined. The technique used to obtain sample aliquots has been described elsewhere (Hopkins, 1962).

Estimation of Error. In a survey of this type it is necessary to determine whether the variation in counts results primarily from irregular distribution of the copepods in the water or from error factors. To ascertain whether the variance of tows at each station was significantly larger than the error factor, the variance of counts, which were adjusted to the average meter reading for each station, was F-tested against the appropriate error term (see

Appendix). Results of F-tests made with logarithm transformed data are given in Table 1. At the .99 level of significance, the variance from all but five stations (W 1–W 4 and S 1) was significantly larger than the error term. The variance of counts of individual species was also investigated and it was found that variances of counts of *Acartia tonsa*, *Oithona brevicornis*, and *Paracalanus crassirostris* in test samples and in samples from stations where they averaged more than 10% of the copepod catch gave F-tests that corresponded well with the results in Table 1.

Results; Tow Variability. Treated in the following results are: the total number of copepods/m3, those species that generally averaged 10% or more of the total count, the number of species, and the index of diversity. Index of diversity, expressed in bits/copepod, was calculated using the information expression (Margalef, 1957):

$$I = .4343/N \; ln \frac{N\,!}{n_1!\, n_2\,! \ldots n_j!}, j = 1, 2, \ldots\ldots, L,$$

where N = total count, n_1 = count for species 1, n_j = count for the jth species where $\sum_{j=1}^{L} n_j = N$, and L = total number of species observed.

TABLE I. Results of F-tests made with the variance of log-transformed copepod counts for each station and the appropriate error variance. The variance subscripts in the Components-of-Error column are explained in the text. The Degrees of Freedom were estimated by the Satterthwaite method (Dixon and Massey, 1957: 134).

Station	Survey (s^2_t)	Components of Error	Error (s^2_e)	Degrees of Freedom	F ratio (s^2_t/s^2_e)
N 1	.266160	$s^2_f + s^2_c/4$	.002690	5,13	98.94*
N 2	.208429	$s^2_f + s^2_c/4$	.002690	5,13	77.48*
N 3	.212679	$s^2_f + s^2_c/2$	.003657	5,20	58.16*
N 4	.042192	$s^2_f + s^2_c/2$	.003657	5,20	11.54*
W 1	.019809	$s^2_f + s^2_p + s^2_c/4$	.005997	5,07	3.30
W 2	.009102	$s^2_f + s^2_p + s^2_s + s^2_c/4$	.007428	5,10	1.23
W 3	.009636	$s^2_f + s^2_p + s^2_s + s^2_c/4$	.007428	5,10	1.30
W 4	.030697	$s^2_f + s^2_p + s^2_s + s^2_c/4$	.007428	5,10	4.13
E 1	.046545	$s^2_f + s^2_c/2$	.003657	3,20	12.73*
E 2	.051713	$s^2_f + s^2_c/2$	.003657	3,20	14.14*
E 3	.059744	$s^2_f + s^2_c/2$	.003657	3,20	16.34*
E 4	.027152	$s^2_f + s^2_c/2$	.003657	5,20	7.42*
S 1	.015631	$s^2_f + s^2_c/2$	.003657	4,20	4.27
S 2	.020269	$s^2_f + s^2_c/2$	.003657	4,20	13.98*
S 3	.051128	$s^2_f + s^2_c/2$	.003657	4,20	5.54*
S 4	.052897	$s^2_f + s^2_c/2$	.003657	5,20	14.46*
S 5	.020647	$s^2_f + s^2_c/2$	.003657	5,20	5.65*

* = significant at $f_{.99}$.

TABLE II. Number of tows included within indicated ranges of the mean total number of copepods/m³, exclusive of nauplii, at each station. The denominator of the fractions indicates the total number of tows taken at a particular station.

Station	$\bar{X}$	$\bar{X} \pm 10\%$	$\bar{X} \pm 20\%$	$\bar{X} \pm 30\%$	$\bar{X} \pm 50\%$
N 1	766	2/6	3/6	3/6	4/6
N 2	1832	2/6	2/6	2/6	3/6
N 3	15160	1/6	1/6	2/6	3/6
N 4	31384	2/6	2/6	3/6	4/6
W 1	13239	2/6	2/6	3/6	6/6
W 2	69768	2/6	3/6	6/6	6/6
W 3	35962	2/6	4/6	5/6	6/6
W 4	24031	2/6	2/6	2/6	5/6
E 1	10526	0/4	1/4	2/4	3/4
E 2	4992	0/4	2/4	2/4	3/4
E 3	10282	1/4	2/4	2/4	2/4
E 4	30678	0/6	2/6	2/6	5/6
S 1	14607	1/5	3/5	5/5	5/5
S 2	15260	0/5	3/5	4/5	5/5
S 3	11590	0/5	2/5	3/5	3/5
S 4	19341	2/6	2/6	2/6	4/6
S 5	15891	2/6	3/6	3/6	6/6

This index was selected because rare species do not affect the index out of proportion to their numbers and because it is very sensitive to fluctuations in proportions of the numerically more important species.

Table II shows the number of tows taken at each station that yielded catches within a given per cent of the mean for that station. At every station at least half of the tows are included within ± 50 % of the mean.

Table III shows the variability, expressed as the coefficient of variation (c. v.) of the total catch, of the index of diversity, and of the counts for *A. tonsa*, *O. brevicornis*, and *P. crassirostris*. It appears from this table that the c. v. of the total catch for a single oblique tow is approximately 43 %. The c. v. for each of the three species is within the range 51–56 % and is thus somewhat higher than the c. v. for the total catch. The index of diversity shows the least variation with an average c. v. of 17 %. It appears then, that a single tow at each station gives a better estimate of the species composition of the population than it does of either the number of each species or of the total number of copepods.

Table IV presents for each station the ranges of: total catch, individual species count, number of species, and index of diversity. These data are included to demonstrate that existing trends may not always emerge clearly from counts of a single tow. For instance, it was found by using the average values for each station that the index of diversity increased linearly with in-

TABLE III. THE COEFFICIENT OF VARIATION FOR THE TOTAL COPEPOD COUNT (T), FOR THE COUNTS OF *Acartia tonsa* (A), *Oithona brevicornis* (B), AND *Paracalanus crassirostris* (C), AND FOR THE INDEX OF DIVERSITY (I) AT EACH STATION. THE AVERAGE COEFFICIENT OF VARIATION FOR THESE SPECIES WAS CALCULATED ONLY FOR THOSE STATIONS WHERE THEY OCCURRED IN EVERY TOW.

	$S/\bar{X}$				
Station	T	A	B	C	I
N1	54.2	54.8	—	—	37.9
N2	62.6	87.6	—	—	17.7
N3	85.8	55.7	65.6	149.5	18.4
N4	41.0	84.3	32.2	36.2	9.4
W1	31.0	34.0	36.0	14.5	8.5
W2	22.4	38.8	26.2	32.3	22.3
W3	20.5	41.9	53.8	25.3	19.4
W4	38.5	47.3	46.5	43.4	10.1
E1	47.1	46.1	62.9	57.5	27.5
E2	42.2	40.0	83.4	50.2	16.8
E3	55.4	35.6	62.1	86.6	14.0
E4	39.5	56.1	75.1	45.4	12.4
S1	24.0	62.4	71.2	39.1	10.1
S2	27.8	—	—	40.2	15.9
S3	47.0	83.0	—	51.6	9.9
S4	55.9	—	—	69.2	6.8
S5	30.2	—	—	30.5	7.8
Average	42.9	54.9	56.0	51.4	16.7

creasing salinity, giving a correlation coefficient of .96. It is doubtful that this trend would have emerged as clearly had only one sample been obtained from each station.

Discussion; Total Catch Variability. A look at the variance of the total catch for each station (Table 1) reveals that the variance is not constant from station to station. In an attempt to ascertain whether any of the hydrographic fluctuations recorded could be responsible for the variation in copepod numbers, correlation coefficients were calculated using copepod count variance, s^2t, and the following:

average change of surface salinity from sampling to sampling (r = .66);
average change of bottom salinity from sampling to sampling (r = .12);
average vertical salinity gradient (r = .80);
average surface current velocity (r = .56);
average bottom current velocity (r = .24).

TABLE IV. Range of the copepod data. Spp. represents the number of species. T, I, A, B, and C as in Table III.

St.	No. of Tows	T/m³	T/m³ Max/Min	I	Spp.	A	B	C
N 1	6	48– 1250	26.0	0.30–0.96	2–5	80–94	—	—
N 2	6	285– 5169	18.1	0.74–1.20	4–6	71–87	—	—
N 3	6	1896–39644	20.9	1.18–1.79	5–11	14–68	8–25	7–76
N 4	6	15532–49883	3.2	1.57–2.08	10–17	7–53	19–27	25–61
W 1	6	8721–18624	2.2	1.61–2.04	5–11	32–46	31–42	19–27
W 2	6	53515–89102	1.7	1.18–1.55	5–6	—	29–57	32–66
W 3	6	24078–44740	1.9	1.48–2.67	8–11	—	13–36	41–60
W 4	6	13026–37324	2.9	1.43–2.27	8–14	—	13–23	47–69
E 1	4	5435–16487	3.0	.23– .47	7–8	94–97	—	—
E 2	4	2163– 7195	3.3	.63– .93	6–8	84–90	—	—
E 3	4	4583–18146	4.0	1.56–2.19	8–14	20–48	14–30	22–45
E 4	6	19153–48153	2.5	1.83–2.45	8–18	—	4–29	40–56
S 1	5	8628–17546	2.0	2.25–2.83	13–20	—	—	30–55
S 2	5	8354–24337	2.2	2.12–2.79	13–18	—	—	36–57
S 3	5	6512–14154	3.2	1.95–2.93	12–20	—	—	32–62
S 4	6	9439–38088	4.0	2.56–3.14	13–23	—	—	10–36
S 5	6	8701–21707	2.5	2.42–3.08	14–18	—	—	31–40

Non-zero correlations at the 95% level of significance were obtained for copepod count variance and three of the above variables which suggests that variability is influenced by more than one factor. The obviously strong correlation, however, is that of count variance with vertical salinity gradient. A possible explanation for this correlation could be that, when vertical stability of a two-layered system breaks down due to increased turbulence (wind mixing) and/or diminishing effects of freshwater drainage, plankton patches become dispersed and a more uniform distribution of copepods is effected. A more uniform distribution of the plankton would be expected to yield less variation from tow to tow.

Reduction of Tow Variability. A single tow at Sts. S1, S3, and S5 in St. Andrew Bay and at every station in West Bay would in all probability have yielded a fair estimate of the mean number of copepods passing by each of these points in the course of the survey. Three previous surveys of the estuarine complex, however, revealed quite large vertical salinity gradients at these stations. If indeed horizontal copepod distribution is strongly influenced by vertical stability of the water, the reliability of a single plankton tow at each of these stations would vary from survey to survey.

Since tow variability may vary with time, means of improving the reliability of tows in approximating the average characteristics of the plankton standing crop at a given point warrant consideration. Several methods for improving the reliability of single plankton hauls have been investigated, such as increasing tow duration, using nets of larger diameter, and towing two nets simultaneously. In increasing tow duration there is the risk of net clogging (Yentsch and Duxbury, 1956), and Winsor and Clarke (1940) have shown that there is little reduction in variance to be gained from increasing net diameter. Apparently, too, the pairing of tows is not very effective in reducing variance, judging from the results of a series of tows made at St. WT. The variance of averages of paired oblique hauls made with Clarke-Bumpus samplers, carried out on a 200 yd. interval, 16 station grid, was insignificantly ($F_{.95}$) less than the variance arising from either of the samplers considered individually. It would seem then, in view of the data presented in this paper, that several single tows spaced over a period of hours are more effective in estimating the average biological characteristics at a particular point than an attempt to filter more water at a single sampling. If it is impractical to sample a station more than once during a tidal cycle, then perhaps only variations exceeding ±50% of the mean for the period of study should be considered significant.

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APPENDIX

Error in the present study can be resolved into two components, a sampling and a counting component. The sampling component stems from variations in the mechanics of collecting samples while the counting component includes errors in identification (considered negligible in this investigation), sample subdivision, and aliquot enumeration.

Sampling Error. This was estimated by counting four 1/100th aliquots from each of 10 test samples collected at St. WT in West Bay. St. WT was selected as a test site because several previous surveys of this area never revealed measurable current velocities. It was believed possible, therefore, to sample the same copepod aggregation repeatedly. A single factor analysis of variance of the counts was made, from which the sampling variance, $s^2{}_f$, was computed.

Counting Error. Since the number of copepods in a sample ranged from under 1000 to well over 200,000, it was necessary to follow several procedures in subdividing samples in order to avoid spending too much time on the more densely populated catches.

a) The number of copepods in 69 of the samples was estimated by counting two or four 1/100th aliquots. The error was estimated by computing the