and physiology between reared and wild larvae and concluded that results on growth, nutrition, and mortality of laboratory-reared larvae should not be related to the field. My study shows that jack mackerel larvae reared with food in 10 l containers were smaller and in poorer nutritional condition than larvae reared in 100 l containers. These container-effects occurred at an early age, i.e., morphological differences were evident 9 d after hatching and histological differences 10 d after hatching. Larvae may grow faster and show fewer signs of starvation in large containers because: 1) there is a lower probability of damage from contact with the walls; and/or 2) the same prey density in a larger container may permit the formation of larger food patches and thereby elevate the actual density of food encountered by the larvae; and/or 3) water chemistry in larger containers may be more favorable.

In contrast to results of the feeding experiments, larvae starved in 10 l containers survived 2 d longer and were larger at age 8 d than those in 100 l containers. This indicates that activity may be affected by container size. Larvae in small containers may be less active, consume energy reserves less rapidly, and therefore live longer without food.

The effect of container size on growth, nutritive condition, and possibly activity in jack mackerel larvae, emphasizes the caution that must be exercised when relating results from laboratory to field conditions. The large container may have had no effect on growth and development of jack mackerel, but survival was poor. Further studies are needed to determine the minimum container size required to simulate natural conditions in the laboratory. Because spatial requirements of larval fish depend on locomotory patterns as well as on genetic adaptations to life near solid surfaces (Kinne 1977), optimum container size will probably vary with fish species. In larval fish experiments, container size is a variable that must be considered with temperature, light, food type and availability, and stocking density.

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EFFECTIVENESS OF METERING WHEELS FOR MEASUREMENT OF AREA SAMPLED BY BEAM TRAWLS

It was the purpose of this study to evaluate the effectiveness of using an odometer wheel to measure distance sampled by a trawl. A 3 m beam trawl has been used extensively in a series of benthic ecology studies off the coast of Oregon at depths ranging between 50 and 4,000 m. Two odometer wheels were attached to the trawl in an attempt to measure the distance covered during sampling. The effectiveness of the odometers was examined statistically from performance data collected during 337 hauls over a 3,950 m depth range. In spite of repeated use and repeated suggestions as to the usefulness (Holme and McIntyre 1971; Menzies et al. 1973) there have been no critical evaluations and few reports of faunal density specifically attributed to odometer wheels (Belyaev and Sokolova 1960; Pearcy 1972; Carey et al. 1973; Bieri 1974a, b).

Methods

Analysis consisted of comparisons of the actual wheel performance with the performance expected of the wheels if working as designed. We were concerned with accuracy and precision. Did the wheels actually measure the distance towed, and how much random variation was there in the wheel counts? Exacting answers to these questions would have required a careful calibration of the wheels under conditions encountered in sampling at various depths. Such a deep-sea calibration would have required more effort than the subsequent ecological sampling. However, partial answers were obtained through the examination of data collected during extensive ecological sampling.

As the trawl was dragged along bottom, the wheels should have rotated with the rotations counted on the hub odometers. Due to friction in the wheel mounts and poor consolidation of the sediment, each wheel slipped some portion of the distance dragged. Thus the wheel counts should have normally underestimated the distance actually towed. We are confident that the wheels did not rotate while in the water column because in those accidental cases where the trawl failed to reach bottom, <10 rotations were registered. On a single haul variation in slippage caused the left and right wheel to register different counts. However, even if biased, the wheel counts should have shown three relationships. First, wheel counts should have been positively correlated with other estimates of distance based on navigational fixes and towing times. Second, the ratios of wheel counts accumulated from all hauls should have provided information on the magnitude of the variation between wheels due to small-scale sediment changes and operational characteristics. Third, if sampling occurred within an area of faunal uniformity, catch size might have been related to wheel count. However, since catch was also determined by the actual, usually patchy, faunal distribution, the absence of positive correlation can not be taken as unequivocal evidence that the wheels did not function as designed.

Estimates of distance sampled based on changes in loran A position or speed $\times$ duration of tow are subject to major random error. In either case the greatest error component is that associated with determining the precise moment the trawl is on and off bottom. Additionally loran A fixes contain an inherent technical error, and speed $\times$ duration estimates are dependent upon accurate determinations of true speed over bottom. Since both of these distance estimates were subject to random error, correlation was the appropriate method of comparison. The raw data were critically examined to remove as much obvious misinformation as possible. If the distance by loran was greater than it was possible for the ship to have gone given speed and current conditions, the tow was excluded. The greatest source of loran A error seems to have been simple operator error yielding tow distances that were far too great.

The beam trawl was made of a thick-walled, hollow aluminum tube bolted across the top of two steel skids. The skids were lined with netting, and an otter trawl type net attached to the trailing edge of the skids (Figure 1). The basic configuration and full operating details have not changed since the initial report by Carey and Heyamoto (1972). This beam trawl had many similarities to those used for fishing since the 16th century (Davis 1958). The bicycle wheels of an earlier version of the trawl were replaced by heavier, spiked aluminum disks to decrease damage to the wheels during launch and recovery and while on bottom. A Veeder Root[1] model 54-794692 (Veeder Root Corp., Hartford, Conn.) hub odometer was attached to the axle of each wheel, counting once each revolution (2 m distance). The counter was housed in a thick-walled brass case filled with silicon fluid to prevent air spaces which might lead to crushing at high hydrostatic pressures. The wheel and its mounting fork were attached to the outside of each skid, free to pivot about the mounting bolt. Surgical tubing was used to restrict the angle of swing. Short lengths of angle iron were welded to the bottom of the skids in front of the wheels. These were intended to protect the wheels and to prevent rotation while off bottom. The trawl was paid out at a ship's speed through water of approximately 2 kn. No weights were placed on the bridle or towing line. The time of bottom contact was estimated by an empirically determined table of wire-out needed to reach bottom. A Benthos model 1170 (Benthos Corp., Falmouth,

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

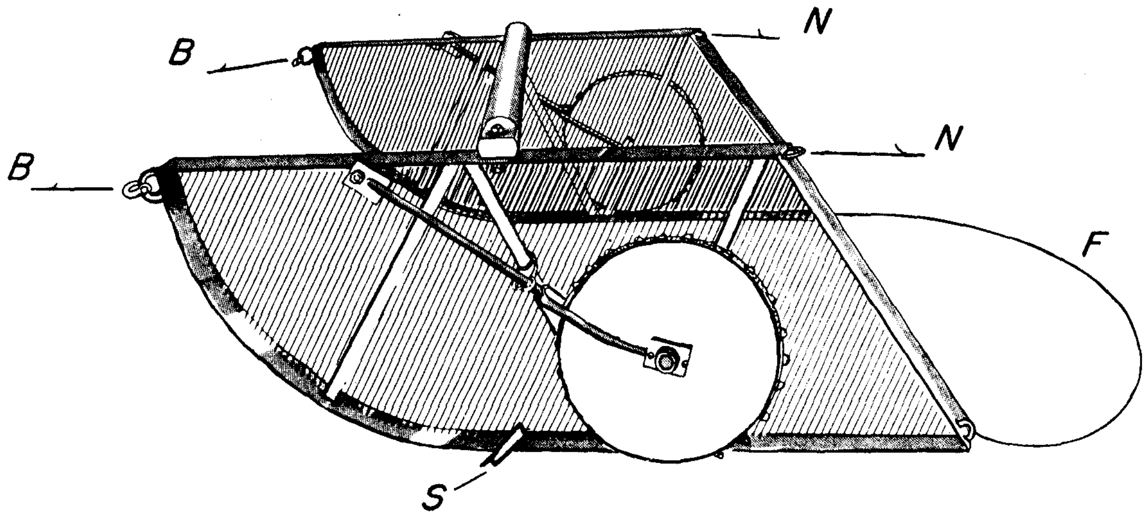

FIGURE 1.—Skid and beam portion of the beam trawl. The towing bridle is attached to the upper leading edge of each skid (points B). The headline is attached to points N. The lateral angle iron extensions (S) are intended to act as stops to prevent wheel turning when off bottom. The skids are lined with netting (hatched areas). The main net is not shown, but the footline is represented by F.

Mass.) time-depth recorder was attached to the trawl, but was lost after only 17 trials.

Results

Consistency of the Two Wheel Counts

Wheel count ratios ranged over a wide span of values. However, there was good agreement between the wheels on about 50% of the hauls (Figure 2) with a ratio of 1.105 or less, and 83% of the ratios were <2.000. Even though the histogram of ratios showed that close agreement between wheels was more common than poor agreement, it was difficult to determine the normal range of random variation. A high ratio might have been due to inherent variation or to mechanical failure of one of the wheels. A wheel might have recorded

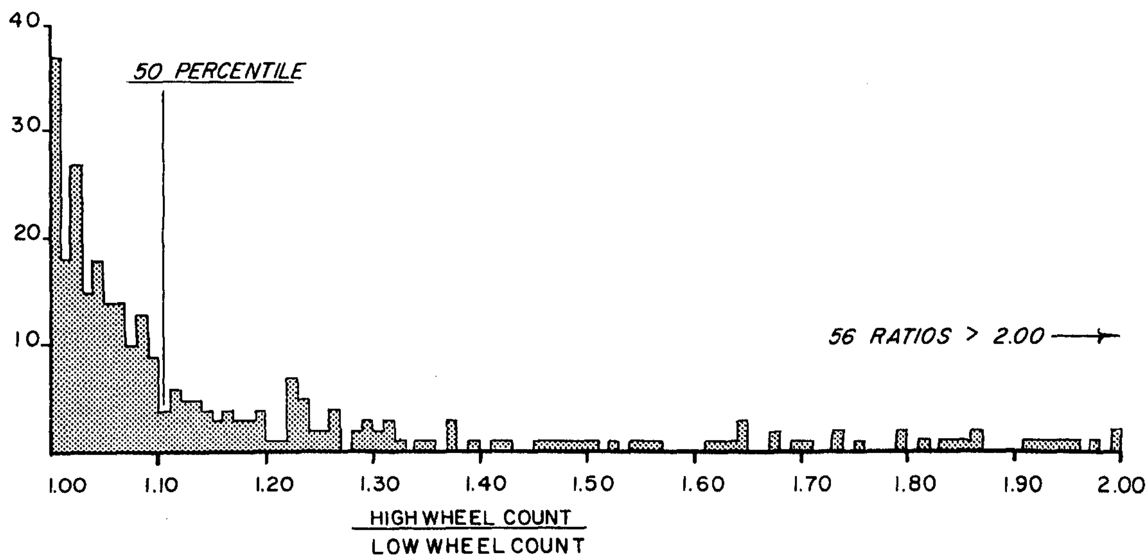

FIGURE 2.—Frequency of occurrence of high:low wheel count ratios, $n = 337$.

a very low count because it was fouled on the net or jammed against the frame during some portion of the tow, but have been in apparently good working order when retrieved. For consistency during subsequent analyses, all ratios >2.000 were considered to be due to a malfunction of one wheel causing a very low reading for the possible distance towed. We feel that this cut off was justified on the basis of the shape of the histogram of ratio frequencies (Figure 2). Seventeen percent of all hauls fell into this malfunction category. The remaining 33% of ratios, between 1.105 and 2.000, represented a high level of normal operational variation. In all cases of ratios >2.000 it was an unusually low wheel reading which produced the high ratio, not an unusually high one. Ratios >2.000 were not further considered in the analyses.

Consistency with Other Estimates of Distance

Wheel counts were significantly positively correlated (95% level) with time duration and loran determined estimates of distance (Table 1), but the correlations were not high. Much more precise estimates of time duration distances were available on the 17 tows employing a time-depth gage. All the gaged hauls were taken between 2,500 m and 3,000 m where bottom conditions were relatively uniform. The correlations between the wheel counts and distance based on gage time on bottom were significant (+0.89 at the 95% level) and much higher than with wire-out determined values. This marked improvement in correlation indicates that errors in determining actual bottom contact time were the major source of difference between wheels and other measures of distance.

The 17 time-depth gage records were compared with the wire-out time on bottom estimates. On average the trawl was actually on bottom 23 min

TABLE 1.—Correlation coefficients between measurements of distance towed. All values are significantly greater than 0.0 (95% level). Asterisk denotes values significantly higher in selected data. Significance was tested following z-transformation. Data selection consisted of removing exceedingly large position changes and samples with a wheel ratio >2.0 (see text).

	Selected data n = 257			
Item	Position	Time	High wheel	Low wheel
Raw data n = 337:				
Position		0.529*	0.638*	0.628*
Time	0.370		.544	.515
High wheel	.183	.591		.972*
Low wheel	.181	.551	.809	

longer than predicted, varying from 75 min longer to 65 min shorter.

The time-depth gage readings were also used to determine a rough estimate of the amount of wheel slippage. Using linear regression the gage measurement of bottom time was taken as the independent variable and the wheel counts as the dependent variable. If the average speed over bottom was the intended 2.0 kn, and if no slippage occurred, then the slope of regression should have been 30.85 (counts per minute). While significantly different from zero, the slope of regression (19.2) was also significantly lower than the expected 30.85 at the 95% level. This major discrepancy may have been due to a ship's speed over bottom consistently much less than 2.0 kn, considerable wheel slippage, or both. If ship's speed over bottom actually did average 2 kn, then an estimate of the worst slippage was 40%. If the ship's speed was consistently low, then the wheels performed better by slipping less.

Wheel Counts Versus Catch Data

No consistent positive relationships were found between the catch of the trawl and the wheel count estimates of distance. This lack of the desired positive correlation was difficult to evaluate because catch was controlled by performance of the trawl and the actual distribution of the fauna. Faunal variation among areas sampled may have masked variation in catch due to differences in distance towed.

In one comparison the echinoderm catch of 22 pairs of consecutive tows in approximately the same bottom area at continental shelf depths was examined. According to wire-out determinations of time on and off bottom all 44 tows were on bottom 20 min. Echinoderm catch was considered because these asteroids, echinoids, and holothuroids represent relatively immobile large benthic organisms. The number of species and total specimens were taken separately as measures of catch size. The number of times the longer haul of the pair (as indicated by the magnitude of the low wheel count on each sample) had the greatest catch was tallied for all pairs of samples and compared against random expectations using a nonparametric sign test (Table 2). While having a greater catch in most cases, the longer tows did not take significantly higher numbers of echinoderm species or specimens.

In addition we examined the catch of the abun-

TABLE 2.—Nonparametric sign test of catch sizes for selected echinoderms in 22 pairs of samples. The long haul in each pair was that with both wheel counts being greater than both wheel counts of the other sample in the pair. When the counts overlapped, the pair was excluded since there was no unambiguous longer or shorter haul. All sample pairs were taken at the same locality on the same day.

Criterion	Highest value in		Significance ($P \leq 0.05$)
	Long haul	Short haul	
Most echinoderm species	15	7	ns
Most echinoderm specimens	16	6	ns

dant megafaunal holothuroids off Oregon at 2,500-3,000 m. The catches for each species were compared with the wheel count estimates of distance towed (based on the average of the two wheels) by computing correlation coefficients. According to wire-out determinations all of these tows were on bottom 120 min. These coefficients were computed with the zero holothuroid catches included and then with zero catches excluded (Table 3). There was no consistent pattern of positive correlation.

TABLE 3.—Correlation of number of specimens of each species of holothuroid with distance on bottom sampled as determined by wheel counts (see text). Correlation coefficients were computed for each species over all samples ($n = 100$) and for only those samples where the species was taken (zeros excluded) to reduce the effects of possible aggregation.

Species	Correlation		No. of hauls	No. of specimens
	All hauls	Zero catch excluded		
Paelopatides confundens	0.043	0.034	90	5,857
Peniagone cf. *dubia*	0.205*	0.201	79	6,133
Scotoplanes globosa	0.044	0.045	75	4,521
Psychropodes longicaudata	0.210*	0.177	68	396
Molpadia musculus	0.011	0.011	33	85
Pseudostichopus nudus	0.061	−0.191	22	48

*$P \leq 0.05$.

Discussion

The earliest reported use of odometer wheels was by Bieri and Bradshaw (cited in Gunther 1957) whose system evolved into a more sophisticated opening and closing quantitative trawl (Bieri and Tokioka 1968). Subsequently, Belyaev and Sokolova (1960), Riedl (1961), Gilat (1964), Richards and Riley (1967), Pequegnat et al. (1970), and Carey and Heyamoto (1972) reported the use of similar devices. Additionally, Wolff (1961) presented a photograph attributed to Zenkevitch of a Soviet beam trawl carrying four odometer wheels similar to those discussed in this report.

Positive correlation between counts, duration, and position change is supportive of the basic contention that the wheels can provide a measure of the distance sampled. However, major questions remain as to the accuracy and precision of the wheels, and the relationship between estimates of area sampled and the catch results. It must be stressed that the positive correlation among distance estimates does not mean that they are either accurate or precise. Our regression of the limited time-depth bottom time estimates on odometer readings indicated that the wheels were inaccurate, being biased by as much as 40% below the actual distance. The numerous low wheel count ratios indicated that the wheels did produce relatively low variance measurements most of the time.

Photographic evidence indicated that the lack of a positive correlation between catch and wheel count might have been due to irregularities that affected total trawl performance, not just the operation of the wheels. Using a camera mounted to the trawl frame it was determined that during a portion of each haul the trawl skids rocked forward, lifting the footline of the net off bottom. The odometer wheels, however, remained in contact with the bottom registering the distance towed. The severe saltations observed by Rowe and Menzies (1967) and Menzies et al. (1973) were not observed in these photographs and did not appear to be a problem with the beam trawl used in this study.

The failure of the footline to constantly tend bottom does not detract from the usefulness of odometer wheels, but it does make it difficult to interpret faunal data in terms of density (Pearcy 1978). Nevertheless, in some preliminary comparisons of trawl versus photographic determinations of faunal densities good agreement has been found. Pearcy (1972) measured populations of the pink shrimp, *Pandalus jordani*, at shelf depths using both techniques and got similar estimates of about 10 individuals/m^2. Similarly Carey et al.[2] measured ophiuroid densities at about 2,500 m and got similar estimates of 2 or 3 specimens/m^2.

Conclusions

The system of trawl frame and odometer wheels used in this study did not produce estimates of

[2]Carey, A. G., Jr., J. Rucker, and R. Tipper. 1973. Benthic ecological studies of deepwater dumpsite G in the northeast Pacific Ocean off the coast of Washington. *In* Proceedings of the First Conference of the Environmental Effects of Explosives and Explosions (May 30-31, 1973), p. 120-137. Nav. Ord. Lab. Tech. Rep. 73-32, N.O.R.D.A., Bay St. Louis, MS 39520.

distance towed which could be used without reservation to estimate the density of fauna. The positive correlation between wheel counts and two other distance measures indicate that the wheels do reflect distance. However, there is so much uncertainty concerning accuracy and precision that it is impossible to decide if apparent faunal density variation is real or an artifact. The real potential of bottom measuring wheels lies in the fact that they are simple, inexpensive, as trawl equipment. For certain sampling problems trawls will remain the sampler of choice. If wheels can be improved then trawl data can be quantified with greater confidence. Future development should focus upon improved precision and a method of field calibration to determine accuracy.

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