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Fluctuation of Longline Shortening Rate and Its Effect on Underwater Longline Shape

Keisuke MIZUNO*, Makoto OKAZAKI* and Naozumi MIYABE

Depth of longline is determined by shortening rate of mainline and elevation due to vertical current shear. Since the shortening rate has not been measured directly, shortening rates used in previous studies have uncertainties. In order to solve this problem, a pair of GPS receiver-installed floats were used for the experimental tuna longline operations in the eastern tropical Pacific during August/September 1997. The shortening rate decreased significantly immediately after setting, which suggests that the shortening rates used in previous studies tend to be overestimated. The shortening rate also changed while the gear was drifting. Fluctuation of the shortening rate is the major cause of depth change of longline when the elevation is small due to weak vertical current shear. Three-dimensional underwater longline shape is estimated by a method proposed by Mizuno et al. (1997) using the observed shortening rate, and appropriate solutions can be obtained in all cases. Obtained shapes of longline are consistent with observed vertical current shear.

Key words: GPS, distance measurement, shortening rate, underwater shape of longline

Introduction

In longline operation, hook depth control is important to make it meet to the swimming depth of target fish species. Basically, hook depth changes in terms of shortening rate of mainline and lift-up effect on mainline and branchline by vertical shear of ocean current, given a certain gear configuration.

The shortening rate, which indicates degree of sagging of mainline, is defined by a ratio of horizontal distance between neighboring floats to mainline length between them. Since detection of vertical shear of ocean current is not easy for commercial fishing boats, they adjust the rate so as to place the hooks at favorable depths. However, shortening rate of deployed gear has not been observed directly. It has been mostly estimated from the ratio of ship speed to mainline releasing speed, which provides only the ratio at setting.

Mizuno et al. (1997) inferred that the shortening rate changed significantly during the gear was drifting from the results of in-situ experiments. Based on time-depth records of micro-BTs (Okazaki et al. 1997) attached to the mainline, they calculated underwater shape of mainline using numerical optimization method, and found that the assumption of constant shortening rate often yielded inappropriate solution of mainline shape.

In order to investigate the change of the shortening rate, we constructed a pair of special floats, which contained GPS (Global Positioning System) receivers, to measure the distance between them. Using these floats, a series of experimental longline operations were conducted in the eastern tropical Pacific Ocean in August-September 1997. The mainline depths were also measured by micro-BTs, and the relationship between the depth of mainline and the shortening rate was investigated. The purpose of this paper is to make clear to what extent the variation of mainline depth is explained by change of shortening rate in actual operation.

GPS Floats for Distance Measurement

Sketch of GPS float is shown in Figure 1. It is a float containing GPS system specified in Table 1. A pair of GPS floats was used in a certain basket of mainline in the operation. The size is approximately the same as other ordinary float. The GPS receiver is able to receive the signals from eight different satellites at a time, and selects the best combination of four satellites among them, which provides the best positioning precision. The received position data were recorded on a memory card at every second.

Typical length of one basket of mainline in actual operation is several hundred meters. Supposing that the length is 500m, distance error of 5m (i.e. 1% of shortening rate) causes 3-5m depth difference at the midpoint of catenary within a range of ordinary shortening rate in commercial operation (Figure 2). For the hook depth control, depth error range of 3-5m might be practically acceptable. Therefore, the error of distance measurement is desired to be less than 5m in standard deviation.

So far, positioning error of GPS is estimated to be 50m in standard deviation (Tsuchiya and Tsuji 1995). However, what we need is not the absolute positions of the floats, but the distance between them. Positioning of one float relative to the other is expected to be more accurate than absolute positioning of single float, which is the same idea as DGPS (Differential GPS). Okamura et al. (1998) conducted an experiment to

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*National Research Institute of Far Seas Fisheries;7-1, Orido 5-chome, Shimizu-shi, Shizuoka 424-8633, Japan.

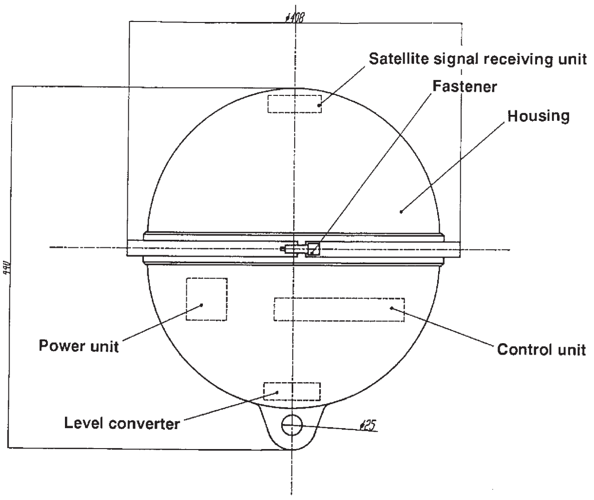

Figure 1. Sketch of GPS float. Specification of each unit is shown in Table 1.

Table 1. Specification of GPS float

Units
- **Satellite signal receiving unit**
  - **PS-5000 (SONY)**
- **Level converter**
  - **IPS-500D (SONY)**
- **Control unit**
  - **Computer : BRAIN PAD (Seiko Electronics)**
  - **Memory card : PCFCA-10M (IO DATA)**
    PCMCIA flush card (10M Byte)
- **Power unit**
  - **U-3 alkaline battery x 12 (8 for receiver, 4 for computer)**
- **Housing**
  - **Plastic (ABS)**
- **Size /Weight**
  - **400mmϕ (408mmϕ Max.)/ 10kg (Buoyancy; 24.5kg)**

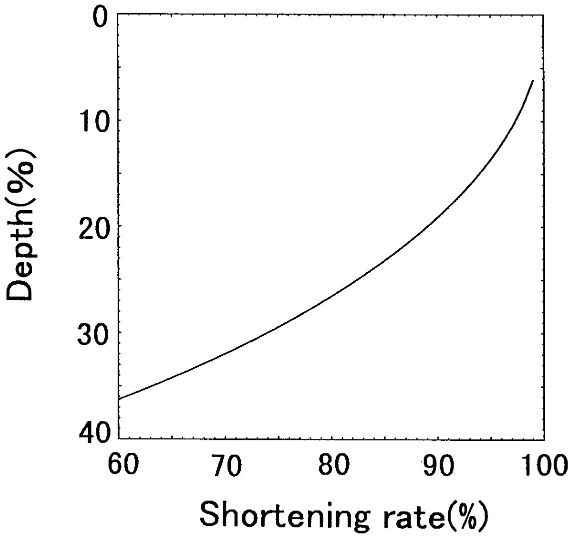

Figure 2. Depth change at the mid-point of mainline in terms of shortening rate in the case of catenary line shape. The range of 60-90% is ordinarily used in actual tuna longline operation.

evaluate the accuracy of the same GPS receiver. They found that the accuracy of 5m in distance measurement is achieved by selecting a pair of concurrent positioning data obtained from the same set of satellites and taking 5 minutes averaging.

In reality, the obtained distance data in the field experiments have frequent spikes. Median filter is generally effective for removing the spikes in data, and it provides more accurate data than simple averaging in this case. Eventually, we applied 5-minutes running median filter on the positioning data (obtained from the same set of satellites), to obtain the distance data for every second.

Field Experiments

In late summer 1997, we conducted field experiments three times in the eastern tropical Pacific by using R/V *Shoyo Maru* (1,360 ton). The locations of the experiments and longline drift of each experiment are shown in Figure 3 with ship track and CTD (SBE 911 plus) observation stations. During steaming, vertical current profile is observed by ADCP (RD 75kHz). Specification of the experiments is summarized in Table 2.

The GPS floats were attached to the float lines of an experimental basket for each operation. The basket number is referred to the retrieving sequence. Since the end of the mainline is comparatively free from constrained force, those baskets near the end of the gear move differently from other baskets. Therefor, end part baskets were not used for the experiments.

Micro-BTs were attached to the mainline at the junction points of branch and float lines (Figure 4), and the temperature/depth data were sampled at every 10 seconds. The mainline has small thread eyes at every 54m in order to be snapped for sure. This is preferable to make the blanchline interval accurate. In the case of Experiment 1, nine branchlines were to be attached in a basket, snapping of the first branchline was failed. Therefore, the total length of the experimental basket is 594m (54m x 11). Sketch of the basket in each experiment is shown in the figure.

Results

Hydrographic condition

The vertical section of temperature approximately

Table 2. Field experiments

	Experiment 1	Experiment 2	Experiment 3
Date	Aug.21,'97	Sept.1,'97	Sept.5,'97
Time	04:35-18:41	08:05-17:08	08:00-17:11
Position	14-32'S	01-56'N	03-05'N
(setting start)	89-57'W	100-01W	99-31W
Hooks per basket	9*	9*	11
Length(m) Between floats	594*	540	648
Basket # /total basket	20/78	25/78	22/64
Wind (Direction/Force)	ESE/6	S/3	WSW/2

*The first micro-BT position to be attached was missed and the total length is longer by 1 branchline interval (see text in detail).

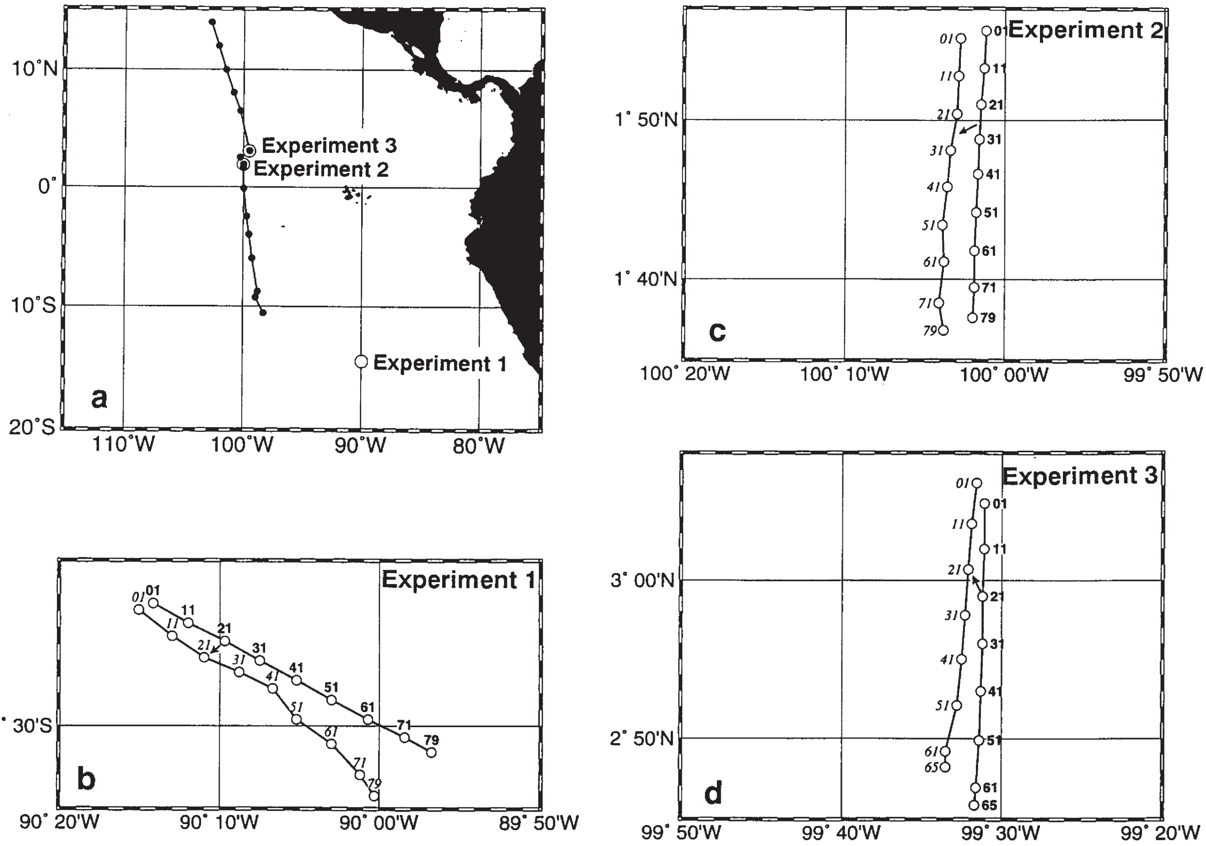

Figure 3. Experimental area and longline drift.Panel a: Location of Experiments 1-3 (open circle) and CTD observation stations (solid circle) with ship track (thin line). Panel b: Experiment 1. Launching and retrieval positions for every tenth float (open circles). The drifting direction of the gear is given by an arrow. Number labels indicate the basket number for the floats. Panel c: Same as panel b, but Experiment 2. Panel d: Same as panel c, but Experiment 3.

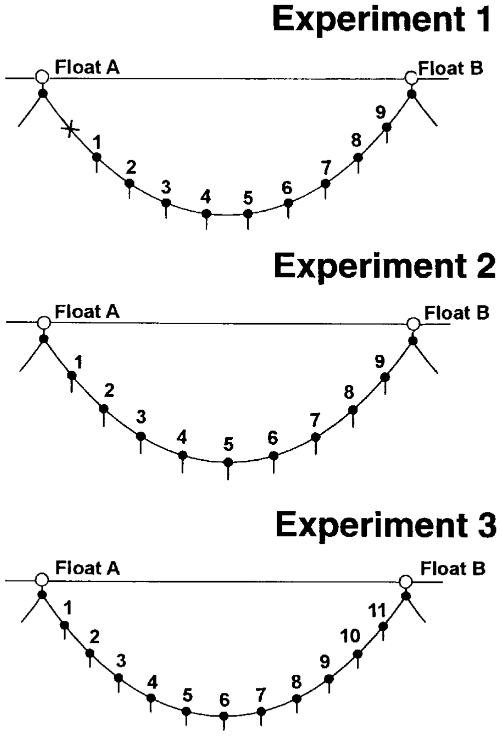

Figure 4. Sketch of used longline gear in Experiment 1-3 (one basket). Attached positions of micro-BTs (solid circles) and GPS floats (open circles) are shown.A cross mark in Experiment 1 indicates a position at which a micro-BT missed being snapped.

along 100W obtained by CTD is sown in Figure 5. It is noted that the temperature of surface mixed layer (28-29°C) is thicker and warmer than normal, and the equatorial upwelling is weak. Such features indicate intense El-Nino condition. In fact, sea surface temperature in the eastern tropical Pacific is higher than normal by 3-4°C (NOAA, 1997).

Generally, the Equatorial Undercurrent (EUC) is tied on the equator, and is identified by a convex lens-like shape of isotherms (i.e. between upward and downward bowing isotherms). It is also noted that EUC located deeper and shifted southward significantly.

Although the location of Experiment 1 is out of the vertical section, it is probably in the South Equatorial Current (SEC) area judging from its location. The location of Experiment 2 is in the SEC area, but that of Experiment 3 is northern edge of SEC bounded by the North Equatorial Countercurrent (NECC).

The zonal drifting pattern of the longline in Figure 3 is consistent with the current system inferred by the thermal field (i.e. geostrophic current) for each experiment.

Experiment 1

The change of shortening rate is shown in the upper panel of Figure 6. The first GPS float was launched at 6:15. The shortening rate rapidly increased up to 92% (i.e. 500m) by the time the next float was launched within a few minutes. Then the rate decreased by 10%

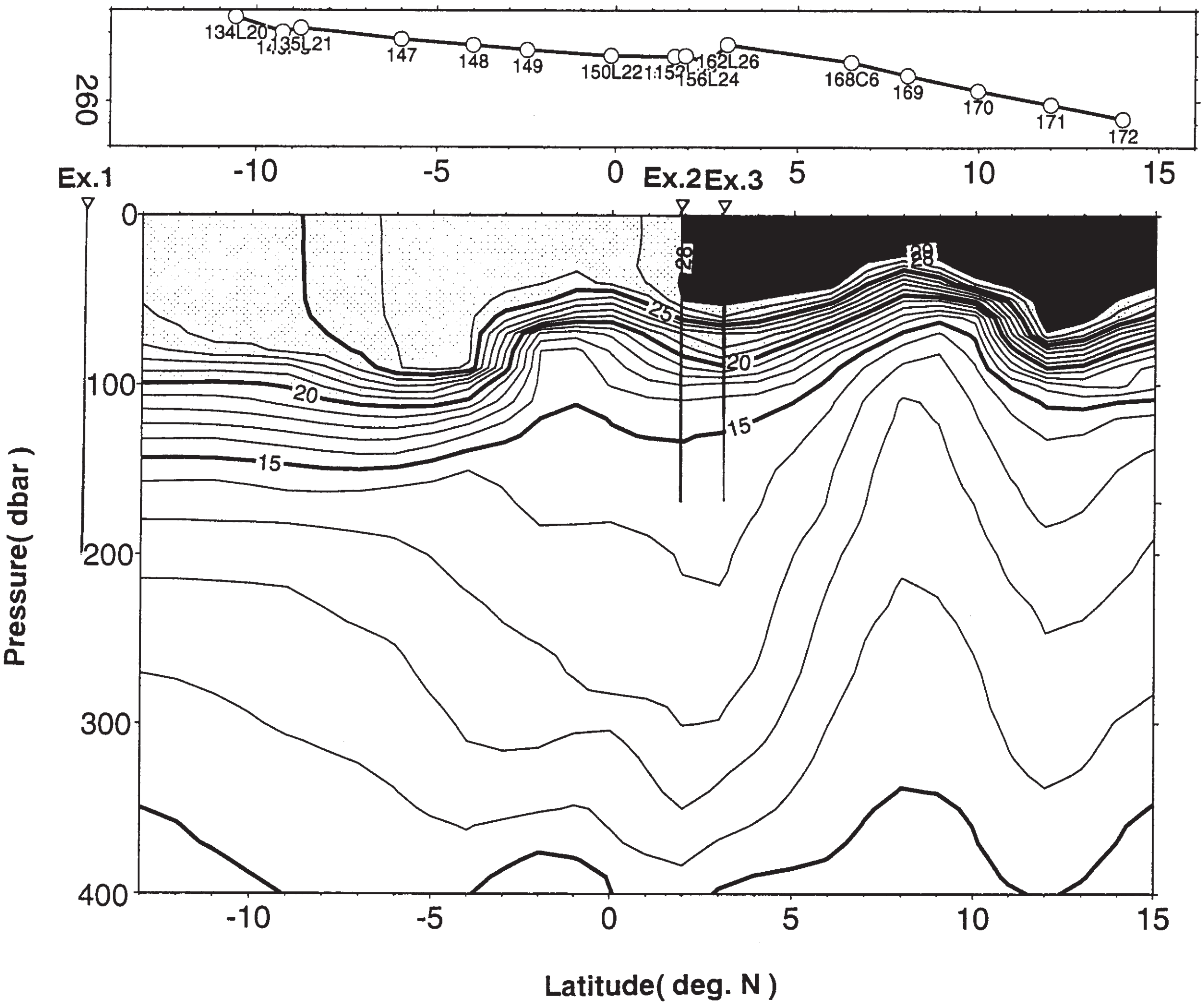

Figure 5. Vertical temperature section along the ship track (in Figure 3a; nearly along 100W) observed by CTD. The section is projected on a meridional plane. Contour interval is 1°C, and light (dark) shade denotes the water higher than 20°C (28°C). The locations of experiments are shown (Ex.1-3). Vertical line at each location denotes the reached depth of mainline.

within half an hour after set. The depth record (thick line in the lower panel) indicates that the line was settled by that time. After settled, the rate fluctuated significantly during drifting. It generally decreased by 20% during the operation. Rapid distance change again occurred at 14:00 just before the retrieving of the latter float. Because its mainline was hauled when the previously basket was retrieved.

Observed depth at the junction point of the fifth branchline and calculated depth by catenary curve were shown in the lower panel. The latter was calculated by assuming a vertically hanging catenary line shape with observed shortening rate. Hereafter it is referred to as catenary depth. In the earlier period (7:00-11:00), the mainline is shallower than catenary depth by 10-20m. It indicates the line was elevated by current shear relative to the line. However, the mainline deepened close to catenary depth in the later period (11:00-). The depth change is almost the same as the catenary depth during the period, suggesting that the current shear weakened and the depth was controlled by shortening rate.

Relationship between the observed depth and the catenary depth in terms of shortening rate is shown in Figure 7 during the line was settled. They are partly correlated, which indicates the mainline depth change is both controlled by shortening rate and elevation by relative current shear. The shortening rate changed from 66% to 79% when settled, which yields more than 40m depth change for the catenary. On the other hand, the vertical current shear elevated the line from catenary by 20m or less. The shortening rate change was more important for the depth change of mainline than elevation by current in this experiment.

Some observed data are slightly deeper than cantenary depths by a few meters. It is explained by measurement error of micro-BT (+/- 1%) and GPS previously mentioned.

Vertical current profiles obtained by ADCP are shown in Figure 8. They were obtained by averaging all data obtained during launching the gear. The current flows southwestward same as the drifting direction. The vertical current shear is weak, which agrees with the relatively weak elevation of mainline.

Since one micro-BT was failed as mentioned in previous section, the underwater shape could not be calculated for this experiment.

Experiment 2

The Change of the shortening rate, observed/catenary

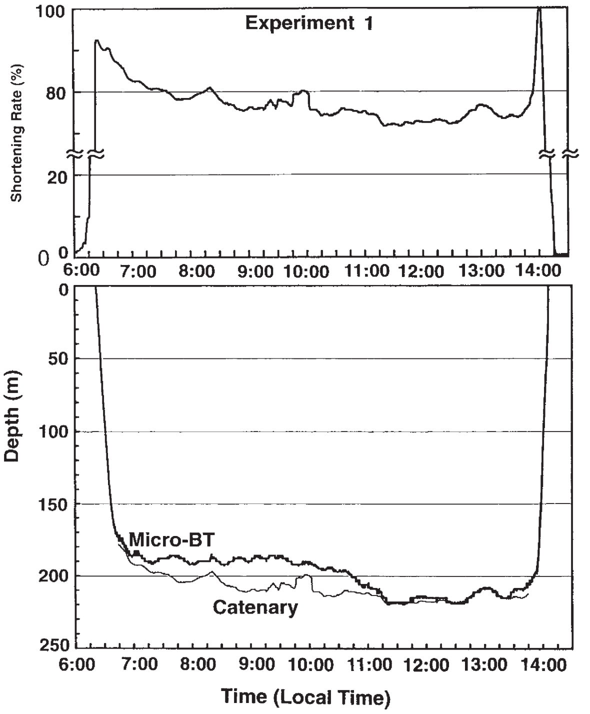

Figure 6. Shortening rate and mainline depth. Upper panel; Shortening rate change (smoothed by five minutes median filter) with time in Experiment 1. Lower panel; Depth change of micro-BT attached to the mainline at the junction point of #5 branchline (thick line) and its catenary depth (see text; thin line). The thin line is shown only for the period when the mainline is reached to settled depths (6:45-13:45).

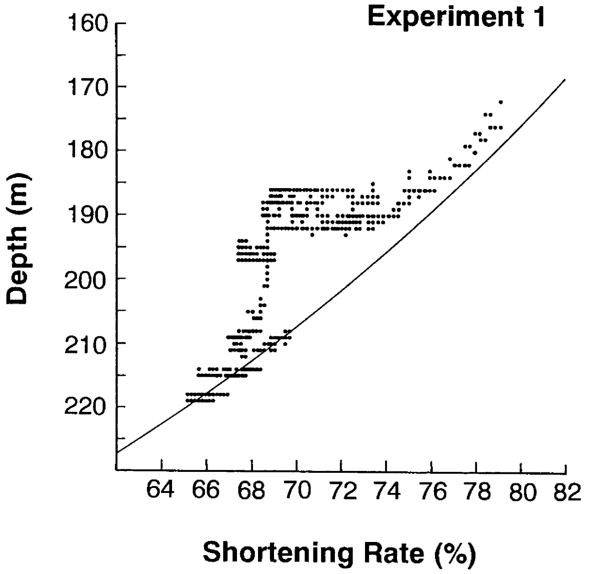

Figure 7. Relationship between observed depth and shortening rate in Experiment 1. Catenary depth in terms of shortening rate is shown by a solid line.

depths at the center of mainline in the basket are shown in Figure 9. After the mainline was released, the shortening rate decreased rapidly by more than 5% until the line is settled (9:00) similarly to the previous experiment. After the line is settled, the rate was rather stable and the range of fluctuation was 64-72% during the gear was settled (09:00-14:00).

Observed depth at the center of mainline was initially much shallower than the catenary depth in the morning. It indicates that the current shear lifted the line by 20-40m. The line slightly deepened and approached to the catenary curve, which suggests the vertical current shear relative to the line became weaker.

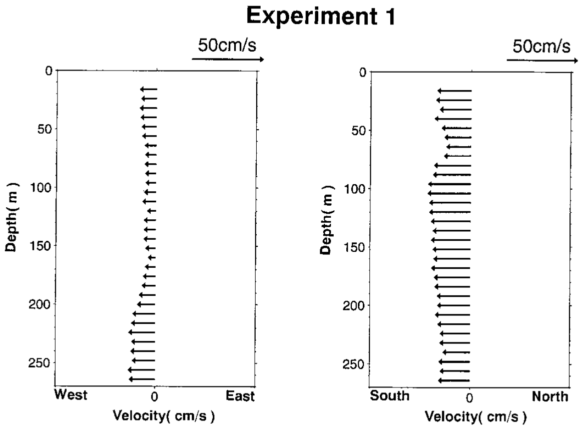

Figure 8. Vertical profiles of east-west and north-south components of current measured by ADCP. The profiles were averaged over the setting time of the longline (a few hours), and the depth interval is 8 m below 16m.

In this experiment, no good correlation between the observed depths and the shortening rate was found (Figure 10). The range of shortening rate change is 64-72% which yields the catenary depth change by 20m. On the other hand, the mainline is elevated by 20-40m by vertical current shear. It turns out that the depth change of mainline is mainly controlled by current.

The vertical current profiles (Figure 11) show southwestward flow in the upper 100m (i.e. SEC), and the southward flow is dominant below it. This current profile is consistent with drifting direction in Figure 3. The vertical current shear is stronger than that in Experiment 1, and the shear elevated the mainline significantly.

Using micro-BT data, the line shapes were calculated for every 15 minutes using the same method as Mizuno et al. (1997). They used a constant shortening rate throughout the operation. On the other hand, we used observed shortening rates simultaneous with the depth data. For all cases, we could obtain the line shapes which satisfy the restricted condition (i.e. total horizontal length is equal to the observed one).

In Figure 12, two shapes at 10:45(shallowest shape) and 13:45(deepest shape) are displayed. Although the sagging rate at 10:45 is smaller, the line is elevated more (panel a, b). The shape is slightly skewed to the south (panel c) due to comparatively strong southward flow below 100m. By subtracting the averaged drifting velocity from averaged current velocity measured by ADCP, relative current to the line was estimated for the line shape (at 10:45) in panel d. The calculated line shape is qualitatively consistent with relative current velocity.

Experiment 3

The line was released with a shortening rate of 91%, and the rate decreased rapidly by 6% within half an hour by the time the line was settled (Figure 13). After this, the line kept stable rate within 5% range during drifting.

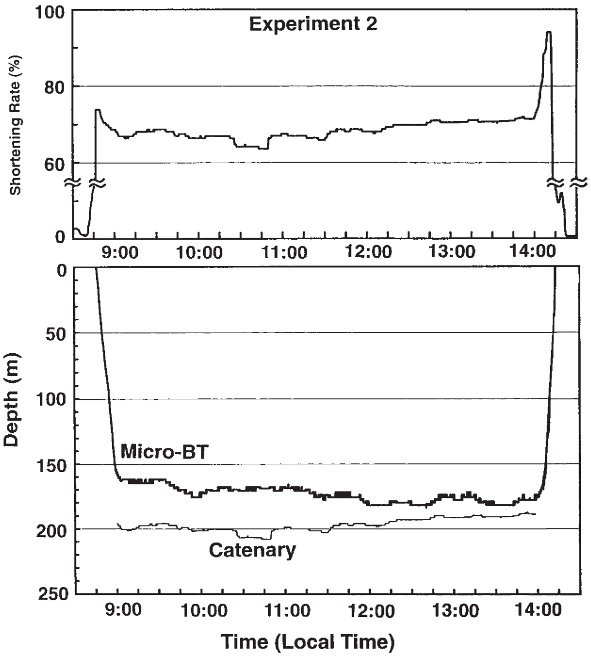

Figure 9. Same as Figure 6, but Experiment 2. The depth records are of the central point of the mainline.

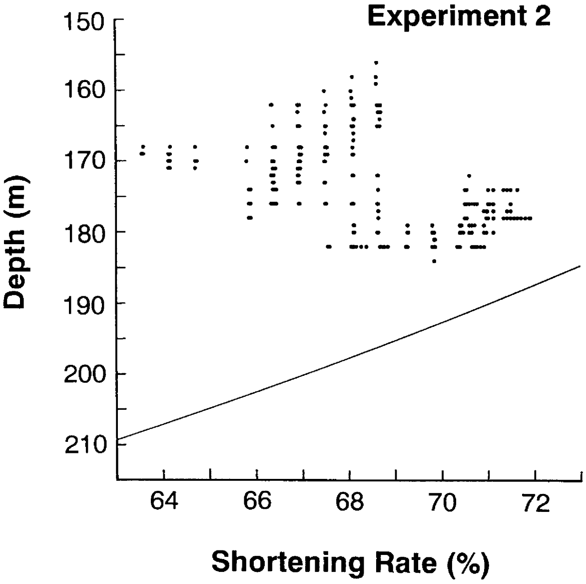

Figure 10. Same as Figure 7, but Experiment 2.

Observed depth at the midpoint of mainline was very close to catenary depth, which indicates the line was nearly catenary shape during the operation. In this experiment, observed depth variation is considerably correlated to the shortening rate (Figure 14). It indicates that the mainline depth is mainly controlled by shortening rate.

The vertical current profiles (Figure 15) show northwestward flow in upper layer and almost no motion in deeper layer. Upper layer current is consistent with drifting direction in Figure 3. The east-west flow is quite thin (nearly 50m), while the northward flow is rather deep (nearly 100m).

The line shapes were calculated for every 15 minutes using the same method as the previous experiment.

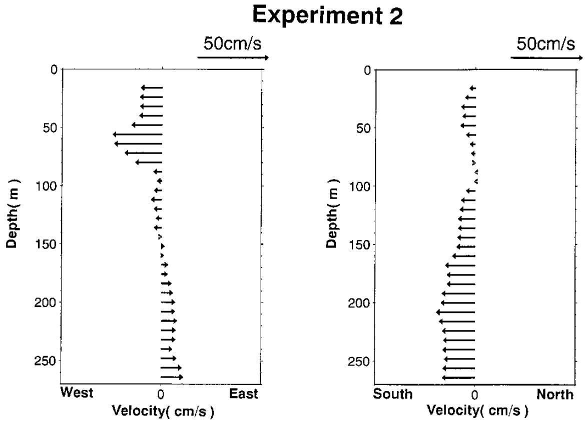

Figure 11. Same as Figure 8, but Experiment 2.

Obtained line shapes satisfied the restricted condition as in the previous experiment. In Figure 16, calculated shapes at 10:00 (the line reached to catenary depth) and 11:45 (the most separated from catenary) are displayed (panel a, b). The shape at 10:00 shows a vertically hanging line.

The front view (panel c) shows that the shape is significantly skewed to the south (panel c) especially below 100m. In fact, the north-south component is stronger than that in Experiment 1. The line has northward component of drifting velocity, and the current below 100m is very weak. Then the line feels southward flow from its side direction particularly below 100m.

The vertical current shear for east-west component is much weaker than the previous experiment. Since the line tended to stay on a vertical plane, there should be no or very weak relative east-west flow. Calculated relative east-west component (panel d) was generally weak (around 5cm/sec) below 50m.

Discussion

1) Shortening rate

In the all three experiments, shortening rate decreased rapidly after setting. This rapid decrease consistently alleviates as the line reached to a settled depth within half an hour. It suggests that the line is strained by its own weight and the floats at both ends are pulled inside. The decrease of shortening rate in this phase ranged from 6 to 10%.

Although the shortening rate changed rather slowly during the gear was drifting, the range of fluctuation is not small (5-20%). The range differed from experiment to experiment. It probably depends upon hydrographic condition.

Shortening rate has been estimated by the ratio of ship speed to releasing speed of mainline (e.g. Hamuro and Ishii 1958, Hanamoto 1987) or the positions of a pair of floats when releasing and retrieving (Mizuno et al. 1997). The results of the experiments suggest that the shortening rates used in previous studies tend to be overestimated. However, observed distance change showed a consistent pattern (i.e., initial rapid decrease and slow change afterward). If we are able to model

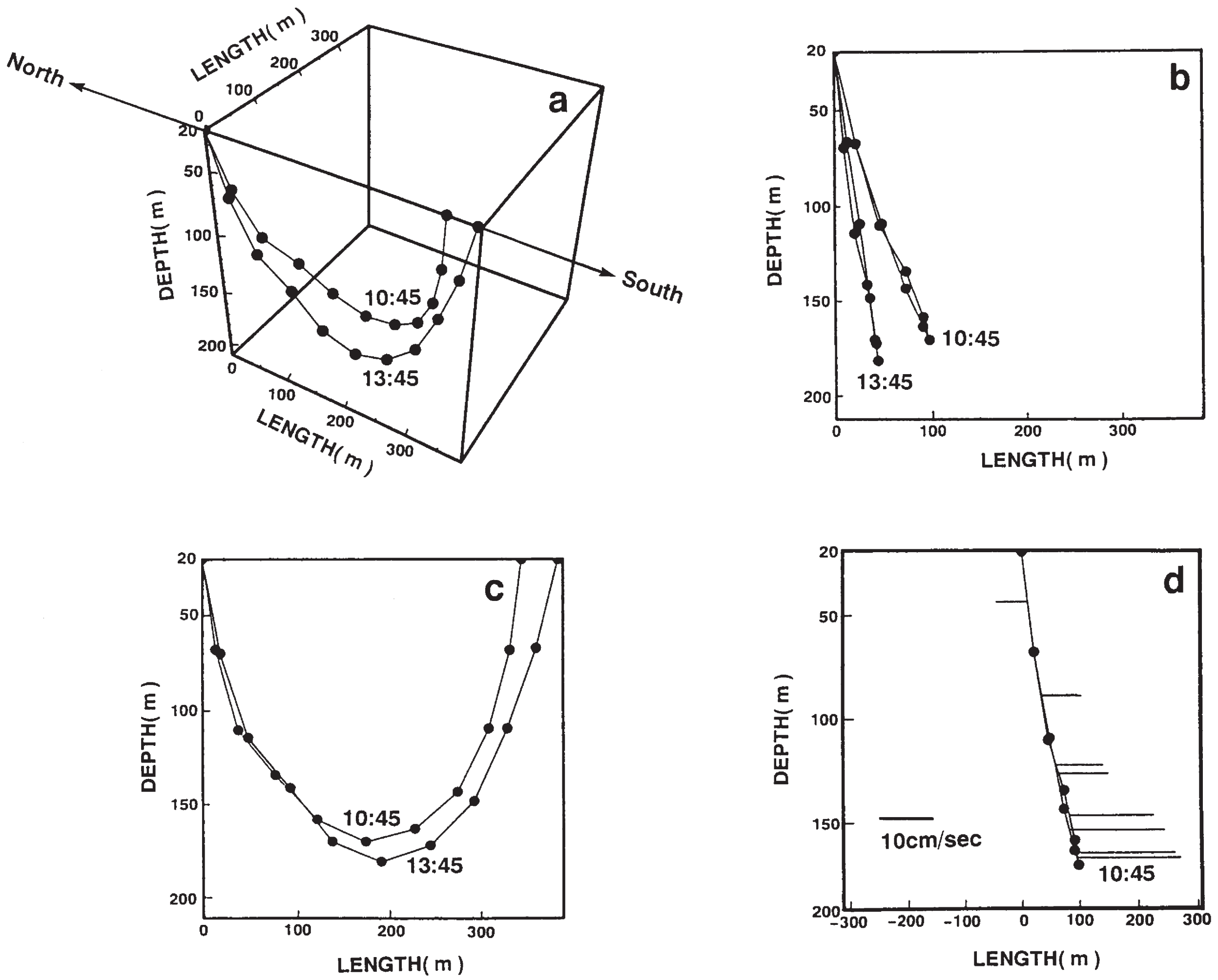

Figure 12. Calculated line shape and relative current. In each panel, depths shallower than float line (i.e. 20 m) are not displayed.Panel a: Calculated main line shapes for Experiment 2 at 10:45 and 13:45. Note that the vertical scale is half of the horizontal scale. Solid circles denote the positions where micro-BTs were attached. The setting direction of main is shown. Panel b: Side view of the line.Panel c: Front view of the line.Panel d: Side view of the line at 10:45 with relative current vector at each line segment.

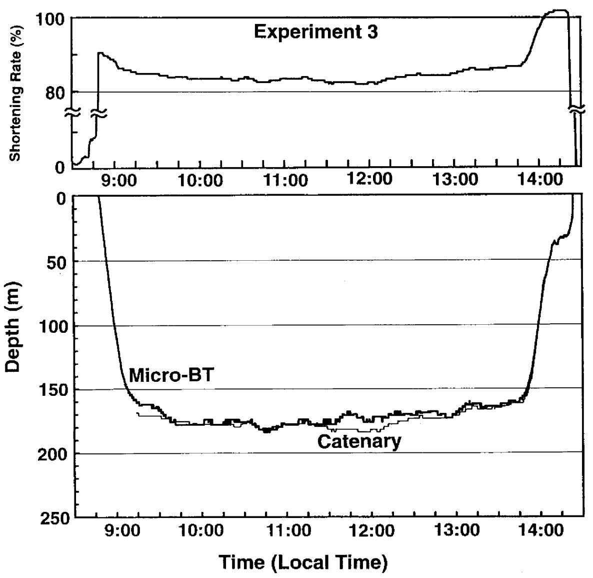

Figure 13. Same as Figure 9, but Experiment 3.

the tendency based on much more observed data, historical shortening rate data may be corrected to a certain extent.

2) Effect of shortening rate on depth change of longline

Depth of mainline is expressed in terms of the shortening rate and elevation by current. Let the depth of mainline at an observed point as d. It can be expressed by an equation

$$d = c - s \qquad (1)$$

where c is the catenary depth determined by a given shortening rate, and s is the elevation by relative current shear. Each term can be divided into average and anomaly parts, as

$$d = \bar{d} + d'$$

where $\bar{d}$ is average and d' is anomaly.

Substitution of this relation in each term of equation (1) and averaging left and right hand sides lead the following equations,

$$\bar{d} = \bar{c} - \bar{s} \qquad (2)$$

$$d' = c' - s' \qquad (3)$$

Averaging the square of (3) is

$$\langle d'^2 \rangle = \langle c'^2 \rangle + \langle s'^2 \rangle - 2 \langle c's' \rangle \qquad (4)$$

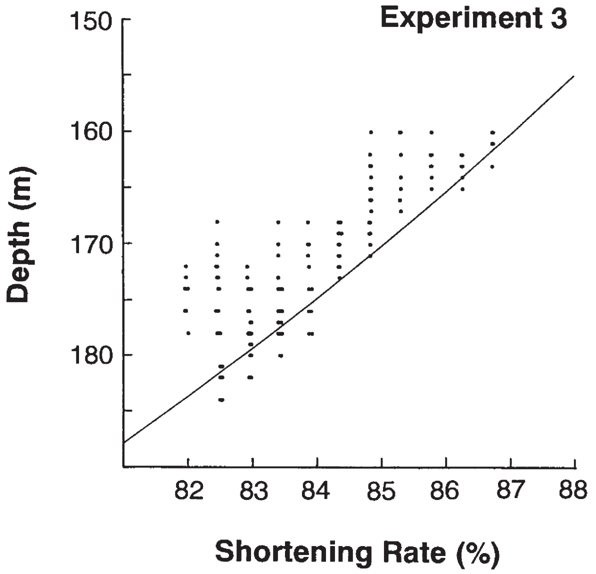

Figure 14. Same as Figure 10, but Experiment 3.

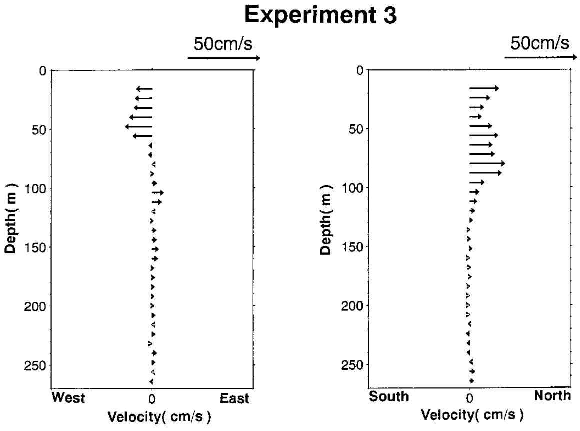

Figure 15. Same as Figure 11, but Experiment 3.

where the angle brackets denote averaging operation. The variance of depth can be explained by three kinds of variances. In the left-hand side of (4), the first two terms are variances of catenary depth and elevation by current shear. The third is the covariance of them. Therefor, in case of *c*' and *s*' are independent each other (i.e. the covariance is zero), the variance of depth can be explained by the first two, namely the effects of shortening rate change and elevation by current shear.

The averaged longline depth is mostly explained by averaged catenary depth in the experiments (i.e. 88-98%) as shown in Table 3. It indicates that the shortening rate is the most important factor to determine the mean depth of longline at least in the experimental area. However, it is not generalized to the area of extraordinarily strong vertical shear. In fact, Mizuno et al. (1997) reported a case that the longline depth is mainly explained by current shear in the Equatorial Undercurrent area.

The variance of longline depth is not equal to the sum of variances of catenary depth and elevation (Table 4), because the catenary depth and elevation are not independent. Therefor, it is hard to evaluate the ratio of their respective contribution to the variance of longline depth strictly.

However, in the cases of small correlation in Experiment 1 and 3 (i.e. -0.24 and 0.25 respectively), the ratio of their contribution might be roughly evaluated. In Experiment 1, the variances of catenary depth and elevation are nearly the same, which shows that the fluctuations of shortening rate and current shear equally contribute to the fluctuation of longline depth. On the other hand, the variance of catenary depth is much larger than that of elevation in Experiment 3, which indicates that the change of shortening rate is the major cause of the fluctuation of longline depth.

Contrary to Experiment 1 and 3, the variance of elevation is much larger in Experiment 2, and strongly correlates with the catenary depth. It indicates that as the catenary hangs deeper due to smaller shortening rate, the line is elevated more by vertical current shear. Such relation helps to keep the longline at a certain depth. In fact, the variance of longline depth is significantly smaller than that of elevation.

3) Underwater Shape of mainline

If we use overestimated shortening rates, the observed mainline is possible to become deeper than the calculated depth by vertically hanging catenary curve. Mizuno et al. (1997) calculated mainline shape from observed depth data and estimated constant shortening rate, using numerical optimization algorithm. They noted that some calculated shapes broke the shortening rate condition (i.e. calculated shape has smaller shortening rate than given one).

Contrary to that, all calculated shapes satisfied the condition with continuously observed shortening rate in this series of experiments. For accurate estimation of underwater shape of mainline, continuously observed shortening rate is necessary.

Elevation of mainline from catenary depth also changed with time. It means that the relative current to the line also fluctuated. Since the calculated relative current is based upon averaged over the time of setting, it is impossible to evaluate the temporal change of relative current strength during drifting. However, general feature of the elevation in each case is qualitatively consistent with averaged relative current velocity. In the area of weak vertical shear in Experiment 1, the elevation from the catenary is generally small. On the other hand, stronger vertical shear caused larger elevation in Experiment 2.

The situation of Experiment 3, which showed smallest elevation, is rather different. It showed significant vertical shear current parallel to the setting direction of the line (i.e. northward component) which yields parallel component of relative current to the line (about 15cm/sec) and asymmetric line shape eventually. However, such parallel-side deformation does not cause the line elevation effectively. On the other hand, vertical current shear of perpendicular to the mainline deployment is quite small (about 5cm/sec). This feature of the vertical current shear makes the line shape hanging closely to a vertical plane.

Although the relation between the mainline shape and the relative current was generally good, a dynamic

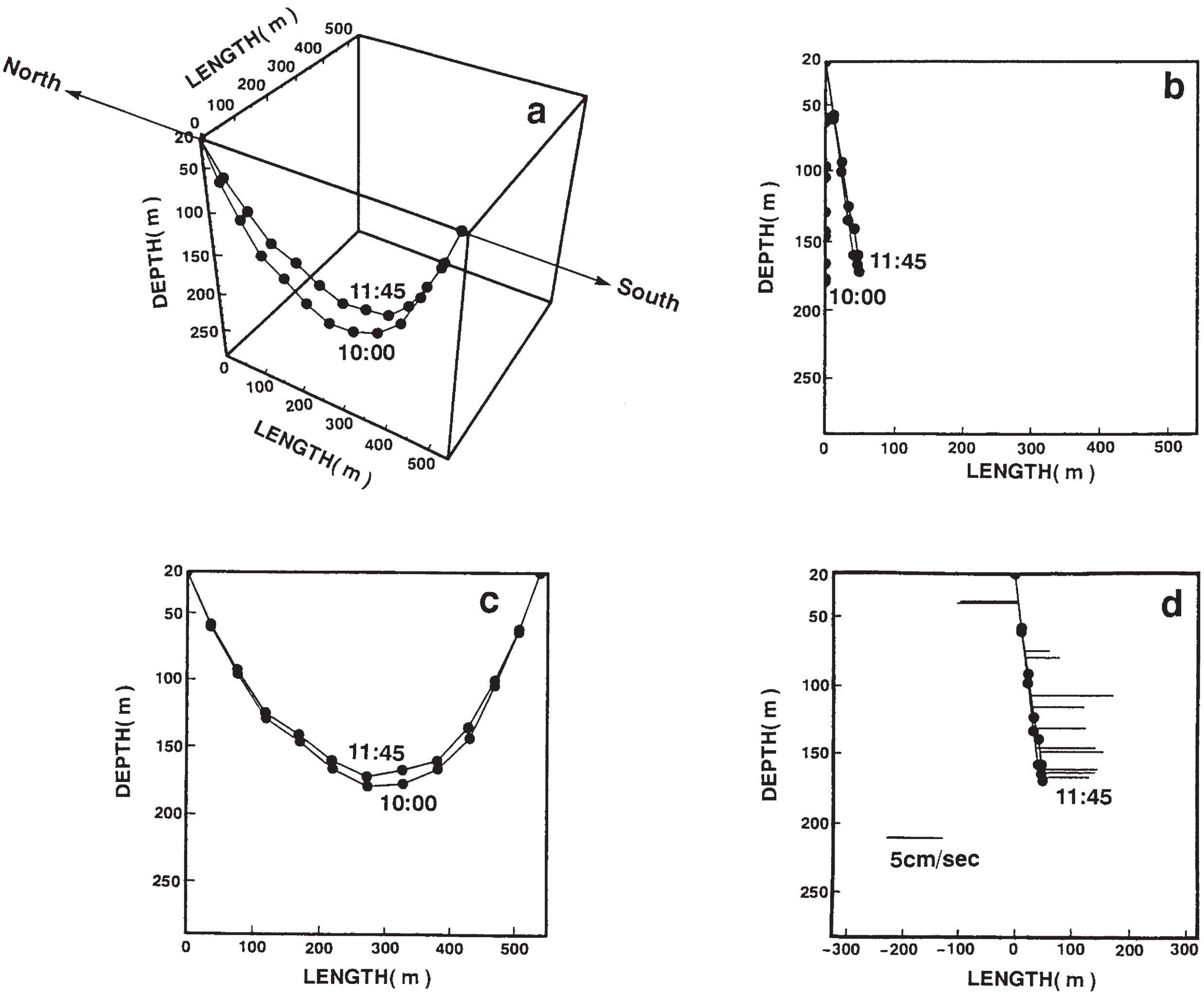

Figure 16. Same as Figure 12, but Experiment 3.

simulation model is necessary in order to understand guantitative relationship. For this purpose, lamped mass model, which is able to simulate underwater line shape under a given current structure, might be effective.

Summary and Conclusion

Direct and continuous measurement of shortening rate of tuna longline has been desired in order to ascertain its real change in operation. It is also helpful to estimate accurate three-dimensional underwater shape of a longline as Mizuno et al. (1997) pointed out. Therefor, we applied GPS system for the measurement of shortening rate, and field experiments were conducted three times in the eastern tropical Pacific. Obtained the major results were as follows:

1) The shortening rate tend to decrease rapidly by several percent within a half an hour after setting by the time of the mainline reached to the settled depths, which suggests that traditionally estimated values tend to be overestimated.

2) After initial rapid decreasing, the rate fluctuated slowly by 5-20%. The degree of fluctuation seems to depend on hydrographic condition.

3) The change of shortening rate is important for the depth change of longline especially in weak vertical shear.

4) By using the observed shortening rate, significant solution of mainline shapes can be obtained without fail in the calculation method Mizuno et al. (1997) proposed. the calculated shapes and observed relative currents were consistent.

5) The current perpendicular to the line setting direction is more effective to elevate the line.

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はえなわ漁具の短縮率変動とその水中形状に及ぼす影響

水野恵介*・岡崎　誠*・宮部尚純*

摘　要

はえなわ操業においては，釣鉤の設置深度は幹縄の短縮率と海中の流れの鉛直シアーによって決まる．しかしながら短縮率の直接計測は今までなされておらず，過去の研究での短縮率の値には不正確さがつきものであった．この問題の解決のため，1997年8～9月東部熱帯太平洋において，GPSを組み込んだ一対の浮子をはえなわ操業に用いて3回の実験を実施した．短縮率は浮子投入後直ちに減少し，過去の研究における短縮率の過大な見積もりが示唆された．短縮率ははえなわ漁具の漂流中も変動したが，流れの鉛直シアーが小さく吹かれが小さい時には，この変動が釣鉤深度変化の主要な原因となっていた．計測された短縮率データから，水野ほか（1997）の方法を用いてはえなわの3次元水中形状を推定した．すべての実験について妥当な解が得られ，その水中形状は観測された流れの鉛直シアーと矛盾しなかった．

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*遠洋水産研究所　（〒424-8633 静岡県清水市折戸５丁目７番１号）