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Long-term Environmental Changes: Interpretations from a Marine Benthic Ecologist's Perspective (II) -Eutrophication and Substratum Properties

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Chemical oxygen demand (COD), phytoplankton cell number and chlorophyll-a concentration (Chl-a), sediment mean grain size and ignition loss were studied to determine their temporal trends in the study area. Historical data of COD, cell number and Chl-a were gathered from the late 1960s or early 1980s to 1997, and trends in temporal domain were obtained from a simple regression. Sediments for grain size and ignition loss (as organic contents in sediments) were sampled from the Chokchon macrotidal flat bimonthly from September 1990 to November 1996, and were analyzed using the decomposition method of time series analysis. In general, the first three data showed increasing trends based on regression analysis. The trends of sediment grain size fluctuated in a neutral pathway while those of ignition loss yielded no increasing pattern. In contrast with the suggestions from Ahn and Choi (1998) who reported a coarsening variation in sediment grain size to be a cause of the directional and remarkable changes of macrofaunal communities in this area, we could not find such a corresponding variation pattern from our samples. In diagnosing eutrophication, a paradoxical phenomenon was encountered between the trends in water column (COD, cell number and Chl-a) and sediment (ignition loss) data. In this paper, we inferred the possible processes that produce the discrepancy. Some explanations and biological responses to eutrophication were predicted and discussed.

Key words: long-term variation, eutrophication, sediment grain size, time-series analysis, tidal flat

Introduction

The potential effects of eutrophication were presumed to affect biological assemblages in a temporal scale (Beukema and Cadée, 1986). A recent study showed that for the most part, temporal variation in the macrobenthic community in a coastal area could be linked to eutrophication (Tagliapietra et al., 1998). In addition, the spatial variation in tidal flat macrofauna is known to be governed by substratum types (Yoo, 1998). Hence, possible changes in these variables will have remarkable effects on the faunal variations.

From May 1989 to November 1996, macrobenthos in the Chokchon tidal flat were sampled at three fixed stations: high, middle and low flats. The sampling was carried out at bimonthly intervals to investigate the temporal variations of faunal assemblages. In this paper, our primary concern is to observe and to discern the temporal variation pattern exhibited by environmental changes or events during the biological sampling period. From the previous study (Yoo et al., 1999), we have shown that a continuous rise in temperature or mild winters in succession characterized this period. By linking this observations with the present study, we described and reported the temporal variation in chemical oxygen demand (COD), phytoplankton cell number, concentration of chlorophyll-a in water column, and mean grain size and ignition loss (measured as organic content) of the surface sediment sample. Not unlike the previous study, the authors weighed the probable effects of abiotic factors on the macrofaunal assemblages in tidal flats.

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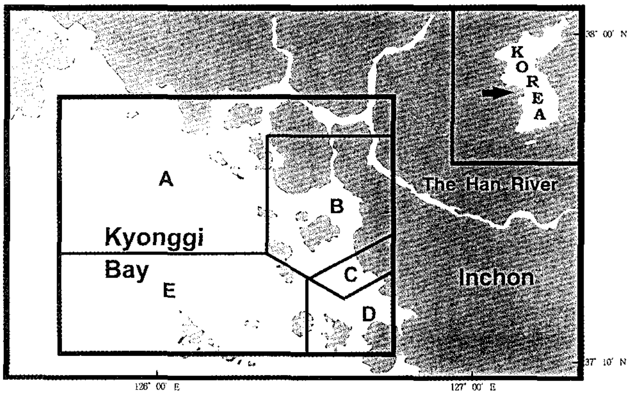
Materials and Methods

Description of the environmental data

To check symptoms of eutrophication, we examined the historical data of COD (chemical oxygen demand), phytoplankton cell numbers and chlorophyll-a in Kyonggi Bay, and sediment ignition loss data from the Chokchon macrotidal flat in the west coast of Inchon, Korea (Area C in Fig. 1). Data for the first three variables were obtained from the related literature. The sources of the studies were listed with the timeframe and study locations in Table 1. Data points of the three variables were 1202, 305, and 322, respectively. By classifying the sampling date of each record, these were converted into monthly and annual averages. Observations and analyses were performed initially on a real scale of Kyonggi Bay, and data were then allocated into five subdivided areas whose environments were suggested to have different potential sources of disturbance (Fig. 1 and Table 1). Temporal variations of sediment grain size were observed from the same sediment samples obtained from the biological stations in Chokchon macrotidal flat.

Analytical method

The trends exhibited by COD, phytoplankton cell number and chlorophyll-a data were analyzed using simple regression. No further analysis for seasonality and periodicity was possible because the data were fragmented and were not equally spaced. The authors supposed that (1) accurate prediction and forecasting based on these data would be



Modified from Hong (in preparation)

Fig. 1. Index map of areas used for checking eutrophication in Kyonggi Bay.
Area A: Area presumed to be in a relatively normal state. Upper parts are affected by freshets from the Han River.
Area B: Area presumed to be under eutrophication, and other sources of disturbance (e.g., construction of Inchon International Airport and harbors). Heavily polluted areas are found in the North and South Port.
Area C: Area presumed to be affected by a large scale of reclamation for the construction of New Songdo City and the LNG (Liquified Natural Gas) Base. The study site of Chokchon tidal flat is included in this area.
Area D: Area in and around the Shihwa Dike. From 1994, the inner part of the dike has been heavily polluted.
Area E: Important areas for protecting coastal fisheries sources.

Table 1. Sources and periods of fragmented data for eutrophication diagnosis in this study

COD			Phytoplankton cell number			Chlorophyll-a		
Source	Study year	Area	Sources	Study year	Area	Sources	Study year	Area
Choi (1984)	81~82	B, C, E	Choi (1984)	81	B, C, E	Choi et al. (1997)	95~96	D
PDBA (1995)	89~90, 92~95	B, C, D	Choi et al. (1997)	95~96	D	Chung (1988)	86~87	B, C, D
PDBA (1996)	96	B, C, D	PDBA (1994)	92, 94	B, C, D	PDBA (1994)	92, 94	B, C, D
KOACA (1994)	93~94	A, B, E	PDBA (1995)	95	B, C, D	PDBA (1995)	94~95	B, C, D
KOACA (1996)	95~96	A, B, E	PDBA (1996)	96	B, C, D	PDBA (1996)	96	B, C, D
KOACA (1997)	96~97	A, B, E	KOACA (1994)	93~94	A, B, E	Kang et al. (1992)	89~90	B, C
NMP (1987)	87	B, C, D	KOACA (1996)	95~96	A, B, E	KOACA (1994)	93~94	A, B, E
NMP (1988)	88	B, C, D	KOACA (1997)	96~97	A, B, E	KOACA (1996)	95~96	A, B, E
NFRDA (1972)	68, 71	B	OSTI (1990)	88~89	B	KOACA (1997)	96~97	A, B, E
NFRDA (1974)	72	B, C	OSTI (1993)	92	B, C, D, E	OSTI (1990)	88~89	B
NFRDA (1975)	74	B, C	Shin (1985)	83~84	B, C	OSTI (1993)	92	B, C, D, E
NFRDA (1996)	89~90, 92~94	B, C, D, E						
OSTI, 1990	88	B						
OSTI, 1993	92	B, C, D, E						
Park et al. (1997)	95~96	D						
Shin (1985)	83~84	B, C						

meaningless, and (2) obtainable and meaningful information would just determine whether increasing trends are present or not. Consequently, the polynomial regression method was not applied along with residual analysis that tests homogeneity of variances and serial correlation. Although the significance of the slopes of the fitted lines was suggested, we did not consider them much and focused on the overall patterns of the estimated slopes.

Sediment grain size and ignition loss data were obtained continuously at equi-intervals (two months) for seven years, and time series analysis was carried out to observe temporal variation patterns. The study employed the decomposition method that divides the obtained variances into three sub-patterns of seasonality, trend and cyclical variation (see Yoo et al. (submitted)). The method assumes that observation Z_t at time t follows the additive model, which is composed of seasonality (S_t), trend (T_t), cyclical (C_t) and irregular (I_t) variations.

$$Z_t = S_t + T_t + C_t + I_t$$

Each component is estimated using regression analysis in the order they were arranged above. Randomness and white noise were tested in the residual analysis. Heteroscedesticity was calculated using White's test statistic.

When the sample autocorrelation for residuals was calculated, we observed if the distinctive pattern in ACFs appeared along the time lags. As presented in Yoo (1998), the results did not yield any serious problem in the final residuals. More detailed explanations about the method are described in Choi (1992), Kim and Choi (1990) and Gaynor and Kirkpatrick (1994).

In this study, only the trends estimated from the seasonally adjusted data were of interest, and other components such as seasonality and cyclical variation were not considered.

Results

COD (chemical oxygen demand)

The yearly and monthly variations in COD in Kyonggi Bay showed rather neutral patterns (Fig. 2a and 2b). This seemed to be due to the peaks which occurred mainly in Areas B and C from 1981~1984. When it was observed in a smaller areal scale, positive trends appeared in all the five subdivided areas of Kyonggi Bay (Fig. 2). The linear trend in Area B was particularly estimated using the data of 1985~1997, because higher values from 1981 to 19 84 were highly influential. Some of the data from Shin (1985) showed extremely high values (20~100 mg/ℓ) which seemingly reflect analytical error, locality or difference in sampling design (serial observation for 24 hours). Accordingly, the observations were removed. The average frequency of the data was about 15 / month. Although higher frequencies were found mainly in the latter part of the study period, a somewhat balanced shape existed along the time axis (Fig. 2h).

Phytoplankton cell numbers

Monthly averages of phytoplankton cell numbers in Kyonggi Bay showed positive trends (Fig. 3b). Among the five areas, only Area C showed an increasing trend while the others were seemingly neutral (Fig. 3). Some areas proved inappropriate

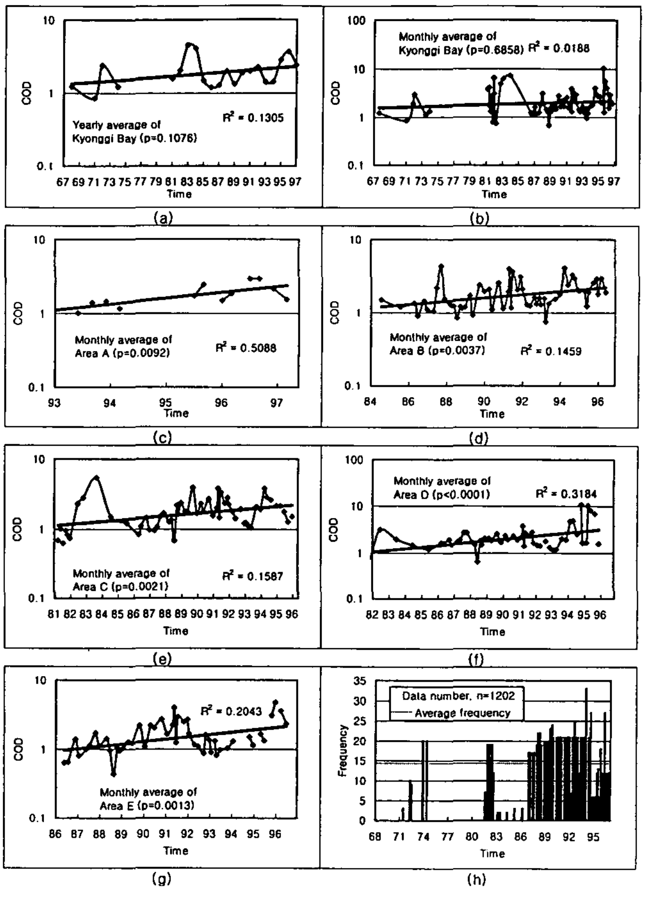


Fig. 2. Yearly and monthly variations of averages of COD in Kyonggi Bay, (a)-(g) and frequencies of the data, (h).

for trend estimation due to the large gaps along the temporal axis (Fig. 3 (e) and (g)). The average frequency of the monthly data was about 8, but lower frequencies were found early on in the study period (Fig. 3 (h)).

Chlorophyll-a

The yearly and monthly averages of Chl-a concentration in Kyonggi Bay exhibited a tendency to increase (Fig. 4 (b)). Positive trends were observed in the monthly averages for areas B, C and D (Fig. 4). The frequencies of the Chl-a data were similar to those of the data for cell numbers (Fig. 4 (h)).

Mean grain size

Sediment mean grain size values at the three fixed stations of the area being examined were analyzed separately. The trends obtained are presented in Fig. 5. There was no increasing or decreasing trend in the deseasonalized data, but

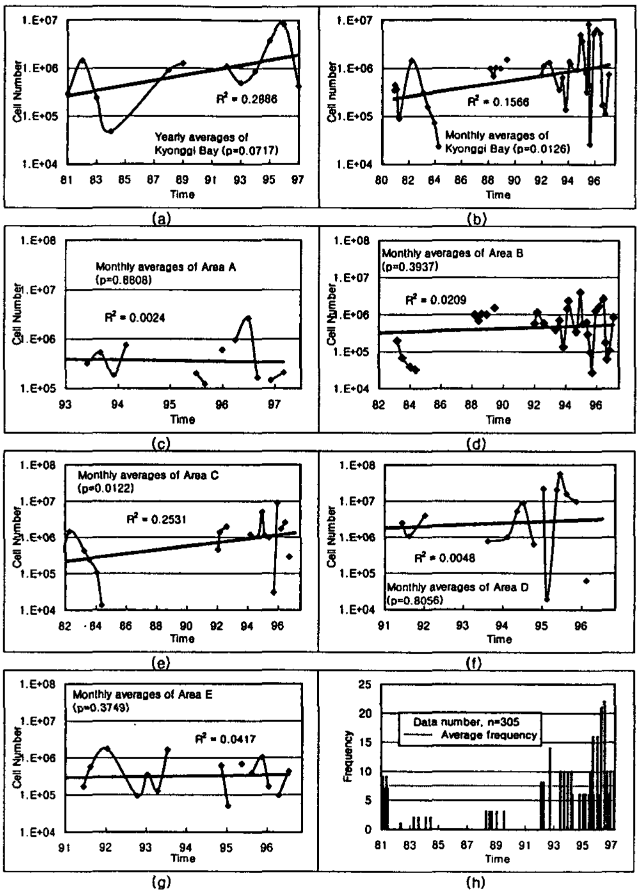


Fig. 3. Yearly and monthly variations of averages of phytoplankton cell numbers in Kyonggi Bay, (a)-(g) and frequencies of the data, (h).

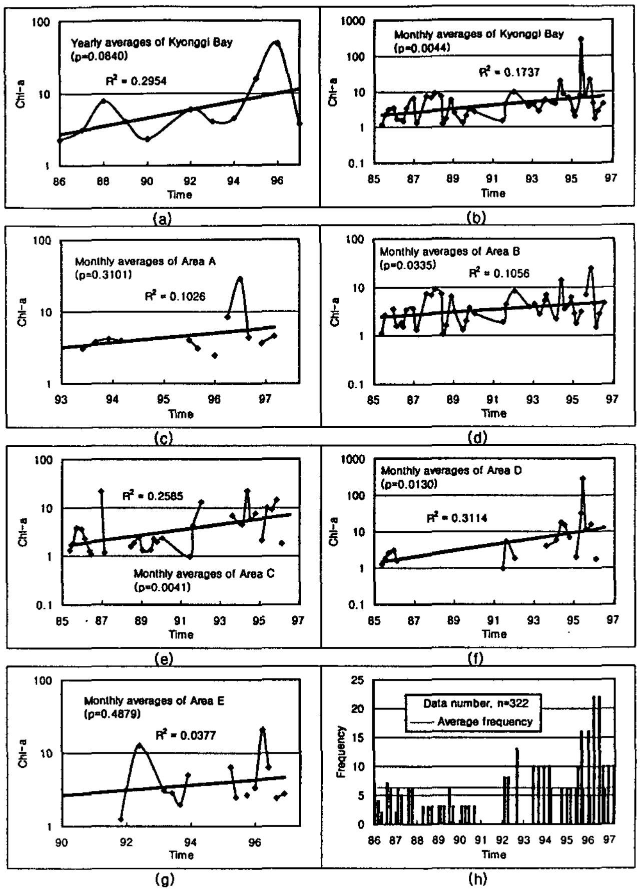


Fig. 4. Yearly and monthly variations of averages of Chl-a in Kyonggi Bay, (a)-(g) and frequencies of the data (h).

they showed some fluctuation. The patterns found in the seasonally adjusted data from the three stations were similar to one another but varied along the time axis. Peaks were also commonly observed in the winter of 1993~1994. However, the trend in the high flat was found to be insignificant.

Sediment ignition loss

In the case of ignition loss, the deseasonalized data appeared to have no increasing trend (Fig. 6), A trend similar with those of sediment mean grain size was observed at St. 1. A somewhat different trend was estimated at St. 2, which exhibited a linearly decreasing pattern. No significant trend was found at St. 3.

Discussion

Temporal trends of water column data

Before we try to compare and observe the fragmented data, a few assumptions have been made to guess or to materialize the limits of the

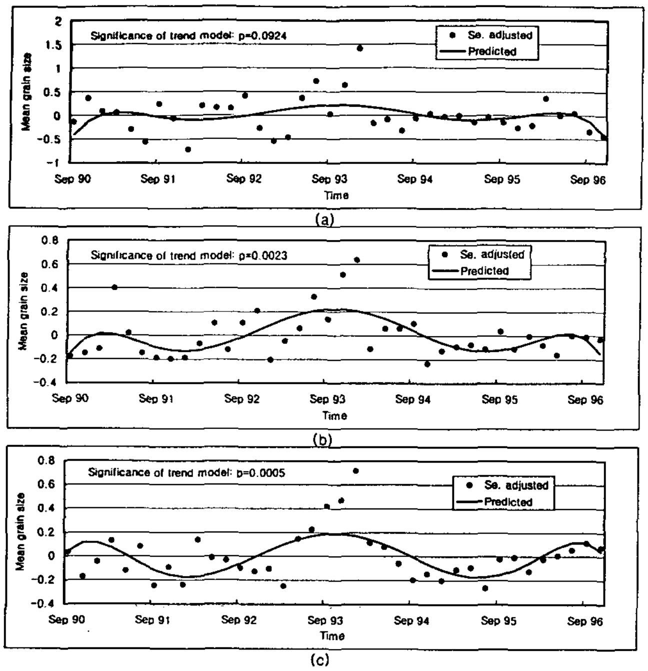


Fig. 5. Trend models of seasonally adjusted data of sediment grain size in high (a), middle (b) and low flat (c).

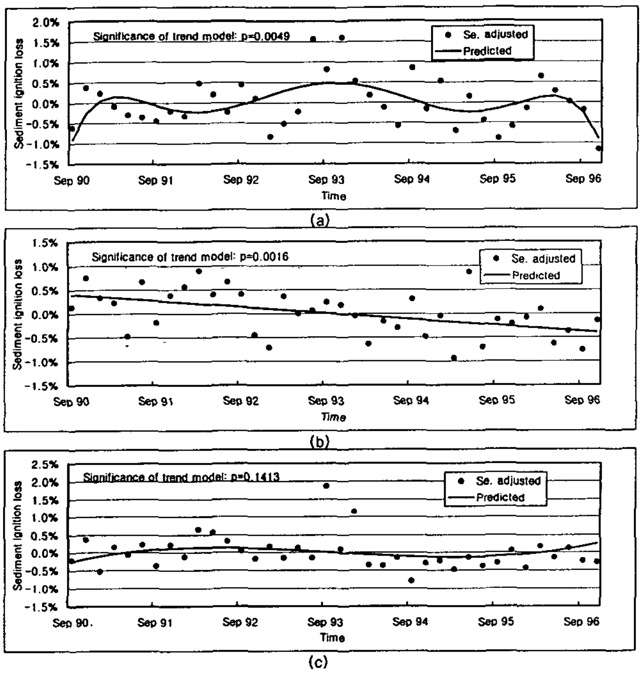


Fig. 6. Trend models of seasonally adjusted data of sediment ignition loss in high (a), middle (b) and low flat (c).

reliability of the estimated trends. The first is that if we observe long-term data with appropriate frequencies, we could estimate a reliable trend that resembles the true one, although the variability in the water column data is high. In other words, the more frequencies the data have, the more reliable the trend we will be able to extract. Secondly, most trends would not be negative because the population of the large cities adjacent to the area being studied, and the artificial interference with the natural environment have gradually increased in recent decades. Thus, pollutant loads in this coastal area may have been increased.

In terms of frequency, temporal patterns of COD were more reliable than any other variables primarily because of the higher frequency for monthly means, the large size of the data (four or five times more than others), and a rather balanced shape of monthly frequencies over time. In spite of the inequality in data properties, the general aspects of the trends of the other two variables were paralleled with that of COD. In relation to the second assumption, it was noticeable that no negative trend was observed from the variables and most of the fitted lines showed a tendency to increase. Hence, violation of these assumptions was unlikely. A coincidental increasing trend found in the variables that reliably indicate worsening water quality and eutrophication was observed in Area C where the study area, the Chokchon macrotidal flat, is located. Although there may be some localized patterns, the estimated trends from Area C seem sufficient to characterize the gradually increasing level of organic pollutants in the biological sampling area used. The positive trend found in the outer area of Kyonggi Bay was regarded as an unexpected result because those areas were previously considered to be in a normal state. The COD and Chl-a concentration in area D significantly increased from 1994, and this was related to the construction of the Shihwa Dike, which is the result of an 'unwise ecology' program and is now a matter of serious public concern (note the extreme values in Fig. 2~4 (f)).

Temporal trends of sediment data

In a previous study, Shin (1988) reported a significant relationship between organic matter influx and the deposition of sediments in this tidal flat. The seasonal variations in the two variables coincided well, and was regarded as an evidence that reflects similar temporal variation patterns (Yoo, 1998).

In higher flats, similar multi-annual patterns were observed in the two variables, although the trends found in the mean grain size data were insignificant.

However, the estimated trends in the middle and lower flats that were inhabited by rich faunas were somewhat different. This may be an indication of the different attributes between the two factors. Ignition loss is a measure of organic content or resources utilized by living things. Variations much more gradual than seasonal scales may be involved in a probable biological process in the area examined, especially in the middle flats.

Recently, Ahn and Choi (1998) proposed a hypothesis that directional variations exhibited by macrofaunal communities in this area are associated with the gradually coarsening grain size of the surface sediment after the seawall construction. However, as shown from the results above, observations from the three fixed stations were not directional but rather fluctuated in a neutral pathway. Hence, their suggestion proved to be non-persuasive.

Expected responses of tidal flat macrobenthos assemblages in the area

A paradoxical phenomenon was observed in that water column variables were positively increased but sediment organic contents showed neutral and even a negative pattern. Increasing levels of COD, phytoplankton cell number and Chl-a in the water column undoubtedly indicate eutrophication and invoke typical responses of macrobenthos inhabiting sediment bottoms (Josefson and Conley, 1997). Recently published articles on the Shihwa Dike present the determined relationship among these variables and the benthic community (Choi et al., 1997; Hong et al., 1997; Park et al., 1997). On the other hand, ignition loss obtained by combustion in a muffle furnace yields 100 % of the total organic matter. This is a useful index of the amount of food available to benthos, and can even be an indication of the amount of food settling in the sediments from the water column (Byers et al., 1978).

If we observed a coincidental positive trend between the variables of water column and sediment grain size, we could conclude eutrophication without any difficulty. At present, we can only guess the possible processes that generate the discrepancy. A similar observation was reported by Maughan and Oviatt (1993) in a mesocosm experimental study. They observed that by adding certain amounts of organic matter or sludge to a differential concentration, sediment organic carbons did not increase, but the biomass of macrobenthic organisms significantly increased. Based on their experiment, we could create a scenario that might occur in the area being examined. Initially, a considerable amount of organic matter was added. Hypoxia, which depresses metabolism, did not transpire owing to the well-mixing characteristics of the water column. The organic matter added was assimilated and decomposed by the efficient metabolism process of the inhabitants, and those assimilated were converted to biomass. Whether this is right or wrong can be proven just by examining the macrobenthos communities in the area.

Many other studies related to eutrophication have revealed that bottom fauna biomass was significantly increased (Beukema and Cade, 1986; Josefson, 1990; Josefson and Conley, 1997). From the previous study on climate variation, the rise in temperature and its effect on tidal flat faunas were predicted and discussed. If the tidal flat community was affected solely by mild winters in succession, the community's biomass would exhibit a neutral or a negative trend (Beukema, 1992). However, an increase in biomass would give evidences of eutrophication, an effective level of eutrophication and the starting point in time, although the exact combined effects of temperature rise and eutrophication are yet to be revealed.

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