J. Fish. Sci. Tech. 2(2), 199~209, 1999

JOURNAL OF
FISHERIES SCIENCE
AND TECHNOLOGY

Long-term Environmental Changes and the Interpretations from a Marine Benthic Ecologist's Perspective (I) - Physical Environment

Jae-Won Yoo, Jae-Sang Hong* and Jae June Lee[1]
Department of Oceanography, Inha University, Inchon 402-751, Korea
[1]*Department of Statistics, Inha University, Inchon 402-751, Korea*

(Received August 1999, Accepted December 1999)

Before investigating the long-term variations in macrobenthic communities sampled in the Chokchon macrotidal flat in Inchon, Korea, from 1989 to 1996, we need to understand how environmental factors in the area vary. As potential governing agents of tidal flat communities, abiotic factors such as mean sea level, seawater, air temperature, and precipitation were considered. Data for these factors were collected at equal intervals from 1976 or 1980 to 1996, and were analyzed using a decomposition method. In this analysis, all the above variables showed strong seasonal nature, and yielded a significant trend and cyclical variation. Positive trends were seen in the seawater and air temperatures, and based upon this relationship, it was found that the biological sampling period of our program has been carried out during warmer periods in succession. This paper puts forth some hypotheses concerning the response of tidal flat macrobenthos communities to the changing environment including mild winters in succession.

Key words: long-term variation, mild winter, temperature rise, tidal flat, macrobenthos, time-series analysis

Introduction

Environmental factors and possible biological interactions govern the distribution and abundance of macrobenthos in a tidal flat. Previous studies carried out in and around the Chokchon macrotidal flat in Inchon, Korea, mainly focused on spatial variation patterns of macrobenthos. These variations were almost always linked to environmental factors such as physiological stress (Koh and Shin, 1988; Lee, 1987), substratum properties (Frey et al., 1987 b), or both substratum properties and physiological stress (Yoo, 1998). Although most of the studies were not carried out using a design that can prove biological interaction (esp. competition), all the results highlighted the importance of abiotic factors in the macrotidal environment. Recently, an inference model of the spatial patterns of principal macrobenthos in the area was reconstructed by using the mean grain size of sediment and the tidal elevation (Yoo, 1998). The successful reconstruction of the biological patterns using the two variables enable to indicate the predominant role of abiotic factors in regulating species distribution.

In a time domain, communities would vary along the temporal changes in the environmental factors (*e.g.*, seasonality, trend and periodicity, etc.). Beukema (1992), Ibanez and Dauvin (1988), Fromentin et al. (1997) and Gray and Christie (1983) have studied the long-term variation in the macrobenthos community. So far, ecological succession has been observed mainly in inter-annual scales of variations, and studies have revealed that the variation patterns paralleled those of distinctive sources (*e.g.*, eutrophication, mesoscale climatic variations, and oil spills, etc.).

Anomalies in these environmental factors frequently occur nowadays, and catastrophic events in biological communities also transpire in this area. However, we could not estimate the effect and dependence of the two events because of the lack of information on past and present variations in

---

*To whom correspondence should be addressed.

the communities. If we could find the regularities and the correlation between abiotic and biotic factors, our understanding of nature would be enhanced, and the possibility of being able to forecast the future would increase. One of the possible derivatives and additional benefits are the ease with which we can recognize and divide the sources of the present variation patterns just by comparing biological samples from a distance (*e.g.*, detection of parallels or deviations as suggested by Gray and Christie (1983)).

From May 1989, macrobenthic assemblages were sampled bimonthly at three fixed stations representing high, middle and low flats to investigate temporal variations. The period might be too short for a discussion of temporal variations to be realistic and for an accurate model to be constructed. However, by observing the variations in the environmental factors as far back as two decades ago, we can investigate the trajectories of temporal variation patterns among the environmental factors. We can also study the characteristics of the biologically sampled periods, and thus match them to the temporal variation in the macrobenthos assemblages discussed in another programmed paper. This paper deals with the temporal variation of environmental factors. Although a discussion on the causalities of the detected patterns may not be possible, the authors weighed the discussion on the probable changes in this macrotidal flat ecosystem.

Materials and Methods

Environmental characteristics

As shown in Fig. 1, the Chokchon macrotidal flat near Inchon is situated along the coastal area of Kyonggi Bay, a coastal plain embayment in the mid-eastern part of the Yellow Sea. Here, a coast has been formed by several islands, including Kanghwa, Yongjong, Yongyu, Daebu and Tokchok, etc (Jang, 1989). Near Inchon, mean neap tides range between 3 and 3.5 m while mean spring tides range between 8 and 9 m (Yi, 1972).

Flood-current velocities range between 0.9 and 1.8 m/sec while ebb-current velocities range between 1.2 and 2.3 m/sec during spring tides (Bong, 1978). At the Inchon Harbor, the maximum salinity of seawater has been recorded at 34.14 ‰ while the minimum has been pegged at 26.63 ‰ up to the present time. The main factor in the variation in salinity is the influx of fresh water discharged from the Han River, which is located on the northern part of the area being studied (KORDI, 1981).

The climate is temperate and the typical pattern of climate controlling conditions in the Yellow Sea consists of the Asian monsoon, which is known to be driven by seasonal variation in polar continental air masses and tropical maritime air masses (Lie et al., 1986). The depositional environment generally represents low-energy conditions, and most tidal flats grade directly into adjacent flats, bayfloor deposits, and sub-tidal channel systems without fronting swash bars or barrier islands and landward salt marshes (Frey et al., 1987a). The area being examined consists of three bottom types of silt in the high flat, sandy silt in the middle flat and silty sand in the low flat. The tidal flat width is about 4 km while steepness is 1.37/1000 on the average.

Description of environmental data

The environmental variables used in this study and their sources are listed in Table 1. The variables are mean sea level (MSL), surface seawater and atmospheric temperatures, and precipitation. As the

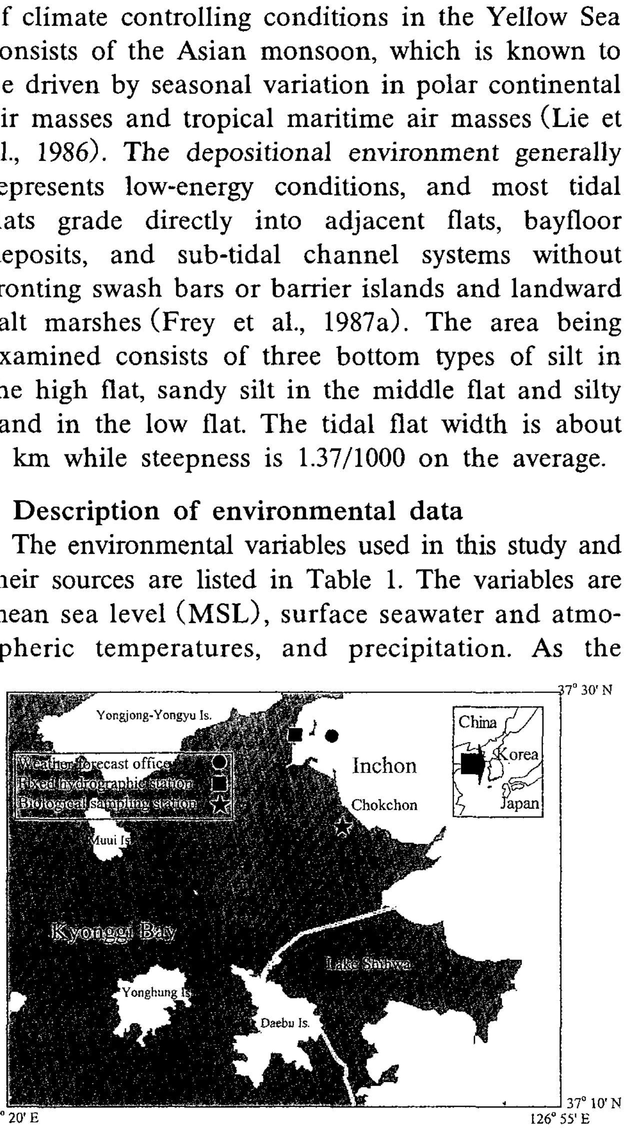

Fig. 1. Location of stations that physical measurements were made. Biological stations on the Chokchon macrotidal flat is marked by ★.

Table 1. Four environmental variables involved in time-series analysis

	Study year	Sources	Sample intervals	Remarks
Mean sea level	1976~1994	NORI	Monthly	National Oceanographic Research Institute
Air temperature	1980~1996	KMA	〃	Korea Meteorological Agency
Sea surface Temperature	1980~1996	KODC	〃	Korea Oceanographic Data Center
Precipitation	1980~1996	KMA	〃	Korea Meteorological Agency

environmental variables were continuously observed at equal intervals (one month), methods of time-series analysis could be applied to investigate long-term variation patterns.

Salinity of the seawater was replaced by precipitation due to (1) its potential as a fundamental source of variability in salinity, and (2) its remarkable effect as a disturbance agent on individuals on an aerially-exposed tidal flat (Peterson, 1991). Data were gathered daily from the coastal and inland stations of national offices in Inchon, and the monthly averages (temperatures, 1980~1996 and mean sea level, 1980~1994) and the totals (precipitation, 1980~1996) were used in a time-series analysis. The MSL data had four missing values which were interpolated using the cubic spline method.

Analytical method

The study employed the decomposition method to perform time-series analysis, although the method gives less accurate forecasts and has a weaker theoretical background. This analytical method decomposes observations into various components, and thus provides information for easier understanding of the sub-patterns found in the time-series model (Choi, 1992). All the following explanations about the method are described in Choi (1992), Kim and Choi (1990) and Gaynor and Kirkpatrick (1994).

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. Each component is estimated using regression analysis.

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

First, the seasonal mean model was applied to the observations, and a trend was estimated from the residuals (the seasonally adjusted data); and then the cyclical variation was estimated from the seasonally adjusted and detrended data.

The seasonal mean model is expressed as follows,

$$y_t = \sum_{j=0}^{12} \beta_j I_j(t) + \varepsilon_t \ (t = 1,2,....,\ \mathrm{T})$$

where $I_j(t)$, the indicator variable, is defined as
$I_j(t) = 1$ when t $\{j, j+12,...\}$ or
0 when j $\{j, j+12,...\}$, where $j = 1, 2, 3, ..., 12$.

Orthogonal polynomial regression was then used to extract trends from the seasonally adjusted data. Orthogonal polynomials of the order p ($p=0, 1, 2, 3, 4, 5, 6$) were calculated and a test of orthogonality was carried out by using model options XPX in PROC REG of SAS (version 6.08 for windows). No significant evidence was found to reject orthogonality.

Because we do not know the order, p, of polynomials, AIC (Akaike's information criterion) and BIC (Bayesian information criterion) were employed in determining p. All of these criteria are expressed as functions of the residual mean square (MSE). Order p of the regression model was selected using multiple comparisons of the minimum value of AIC (upper limit) and BIC (lower limit) as follows. Initially, the lower limit was selected based on the principle of parsimony, and then fitting procedures of the cyclical component were applied to the deseasonalized and detrended data. When there were difficulties in parameter estimation or when final residuals from the cyclical variation model did not satisfy the assumptions of the error distributions (*e.g.*, occurrence of significant autocorrelation in residuals), the procedure returned to the trend estimation step. The seasonally adjusted data were then again fitted using a higher order of p selected based on AIC.

In extracting the cyclical variation, the authors used a trigonometry model. To determine the period of the series, we simply used a periodogram obtained from the observed series and picked out the significant periods. Regarding the sine and cosine function for each period which serve as the independent variables, we choose the best-fitted regression model using selection statistics such as AIC, and BIC. After this, the randomness and heteroscedesticity of the residuals were tested.

For the randomness test, option WHITETEST in PROC SPECTRA of SAS was used and white noise for the residuals was tested using Fisher's Kappa test statistic. The critical values for $p=0.05$ were 7.378. When the observed value exceeds this, further extraction of cyclic variation from the residuals was then carried out. Heteroscedesticity was tested using White's statistic and the option SPEC in PROC REG of SAS. The sample autocorrelation for the residuals was calculated and from this procedure, we observed if the distinctive pattern in ACFs appeared along the time lags. The significance of ACFs was determined using two standard errors.

In the time line of forecasting, the period is partitioned into two distinct periods, the *ex post* and *ex ante* forecasts. The *ex post* forecast period is defined as the time from when the first observation was made after the end of the sample period, to the most recent observation. The *ex ante* forecast period is defined as that time when no observation on the time-series variable is present (Gaynor and Kirkpatrick, 1994). In the case of the MSL, the sample period was confined to 1976~1994, because there was no data available from 1995. This necessitated forecasting into the future. Based on data from 1976~1994, a year of *ex ante* forecast was obtained. To evaluate the out-of-sample forecast accuracy of the model, *ex post* periods of 1994 were forecasted from the data obtained from 1976-1993 and were compared to the observations made in 1994.

Results

Mean sea level

The monthly averages of mean sea level (MSL) are shown in Fig. 2a. When the seasonal mean model was applied, a strong seasonality was found ($p<0.0001$). The monthly averages varied between 435 and 475 cm, recording low figures during winter and high figures during summer. Seasonally-adjusted data were fitted using a trend model ($p<0.0001$), and a slightly hypobolic trend was observed (Fig. 2b). Seasonally adjusted and detrended data were fitted with 19 cyclical components, including periods of 4 and 6 years (Fig. 2c), using a cyclical model.

In Fig. 3a, the residuals, when plotted, proved to be random and featured homoscedesticity. The ACFs of the residuals from forecasts based on 19 76~1994 and 1976~1993 data are displayed in Fig. 3b and 3c. All ACFs of the residuals were statistically equal to zero and showed no distinctive patterns along the lags. Although the decomposition method is not powerful in forecasting, we tried a year forecast of the ex ante period (1995) (Fig. 3d). Forecasts for 1995 generated from data gathered from 1976~1994 and those of 1995 and 1994 based on data collected from 1976~1993 coincided well with each other. For the most part, a seasonal mean model (99.98%) explained the total variation in the MSL data. A trend model explained 0.003% of the total variation in MSL while the cyclical variation model explained 0.008% (Table 2).

Seawater temperature

Seawater temperature also yielded a strong correlation with the season, so a seasonal mean model was fitted with a significance of $p<0.0001$, resulting in r^2 of 0.9936 (Fig. 4a and Table 3). The

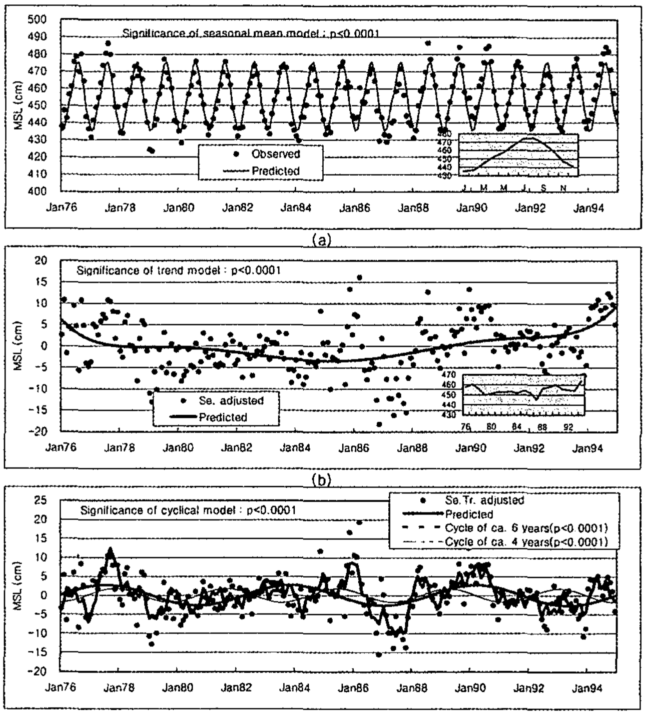

Fig. 2. Decomposition of each component from mean sea level data. ((a) observed MSLs with interpolated intervals and seasonal mean model; (b) trend model; and (c) cyclical variation model)

Table 2. Percent and cumulative percent of MSL data variance explained by the seasonal mean, trend and cyclical variation model and their significance

	Sum of Squares	Percent	Cumulative Percent	R-square	F-value	Prob>F
Seasonal mean	47208690.650	99.983%	99.983%	0.9998	103405.228	<0.0001
Trend	1559.138	0.003%	99.986%	0.1897	17.484	<0.0001
Cyclical variation	3652.602	0.008%	99.994%	0.5486	13.366	<0.0001
Error	3005.989	0.006%	100.000%			
Total	47216908.380	100.000%				

Table 3. Percent and cumulative percent of seawater temperature data variance explained by the seasonal mean, trend and cyclical variation model and their significance

	Sum of Squares	Percent	Cumulative Percent	R-square	F-value	Prob>F
Seasonal mean	49154.261	99.362%	99.362%	0.9936	2493.533	<0.0001
Trend	88.839	0.180%	99.542%	0.2817	19.508	<0.0001
Cyclical variation	77.567	0.157%	99.699%	0.3424	7.065	<0.0001
Error	148.997	0.301%	100.000%			
Total	49469.664	100.000%				

total variation in water temperature was explained by 99.362%. In Fig. 4b, a gradually increasing trend was found in the seasonally adjusted data for seawater temperature. This trend was characterized to be generally lower in 1980-1988 and higher in the latter part of the period. The computed variance of the cyclical terms was smaller than that of the trend, and significant cycles of the period of ca. 0.5 and 1 year were obtained (Fig. 4c).

The results of the residual analysis are presented in Fig. 5a and 5b. Residuals chiefly ranged between ± 1℃. There was no pattern in residuals along the time axis, and all ACFs were considered to be zero.

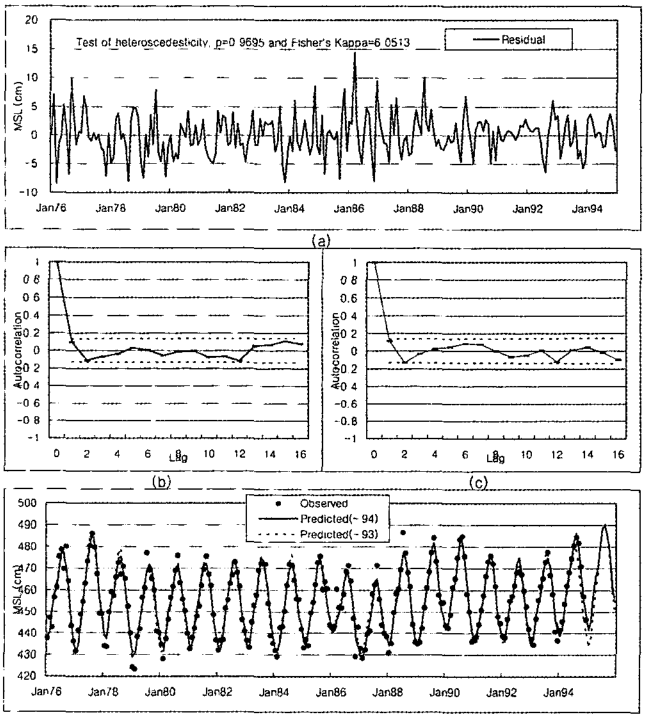

Fig. 5. Result of residual test (a) (c) and observed values and final forecasts (d). (b) and (c) are ACFs of residuals from the 76~94 and 76~93 model, respectively. A year of ex ante forecasts (1995) and ex post forecasts (1994) are presented in (d).

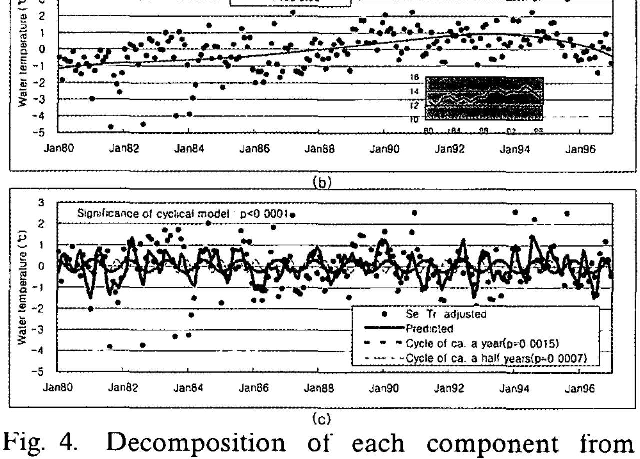

Fig. 4. Decomposition of each component from surface seawater temperature data. ((a) seasonal mean model; (b) trend model; and (c) cyclical variation model)

The temporal pattern of surface seawater temperatures indicated that a slight temperature rise existed in the later period, especially during winter (Fig. 5c).

Atmospheric temperature

Observed data for air temperature were fitted with a seasonal mean model (p<0.0001). For the most part, the variance was explained by a seasonal component (99.332%) (Fig. 6a and Table 4). Although it was less significant in terms of its variance (0.071%), the air temperature gradually increased during the data collection period as did seawater temperature. This was observed in the yearly averages presented in Fig. 6b, and a linearly

Table 4. Percent and cumulative percent of air temperature data variance explained by the seasonal mean, trend and cyclical variation model and their significance

	Sum of Squares	Percent	Cumulative Percent	R-square	F-value	Prob>F
Seasonal mean	45545.530	99.332%	99.332%	0.9933	2377.973	<0.0001
Trend	32.779	0.071%	99.403%	0.1070	12.037	<0.0001
Cyclical variation	87.333	0.190%	99.594%	0.3191	7.499	<0.0001
Error	186.338	0.406%	100.000%			
Total	45851.980	100.000%				

increasing pattern was established with lower values in the anterior and higher ones in the posterior part from 1980 to 1996. Seasonally adjusted and detrended data of air temperature showed cyclical variations of one and six years (Fig. 6c).

Dispersion of the residuals was generally confined to a range of $-1 \sim +1$℃ and the randomness and homoscedesticity of the residuals were verified (Fig. 7(a)). All ACFs were statistically equal to zero. Like the seawater temperature, air temperatures were relatively lower in the former period while higher temperatures were found in the latter part, especially during winter.

Precipitation

When monthly totals of precipitation were fitted using a seasonal mean model, a strong seasonality divided into dry (October - May) and rainy (June-September) seasons, was observed (Fig. 8a). The significance yielded in the seasonal mean model was less than 0.0001. Trends were found to be insignificant; thus, seasonally adjusted data were fitted using a cyclical variation model. A period of ca. 9 months in the data was found to be significant. It explained 10.99% of the total variance (Fig. 8b and Table 5).

Test statistics and plots of ACFs of the residuals reflected randomness, as shown in Fig. 9a and 9b. In Fig. 9c, plots of observed and predicted values are presented. Higher precipitation was observed in the latter part of the study period, and some data did not fit well to the model (*e.g.*, extreme

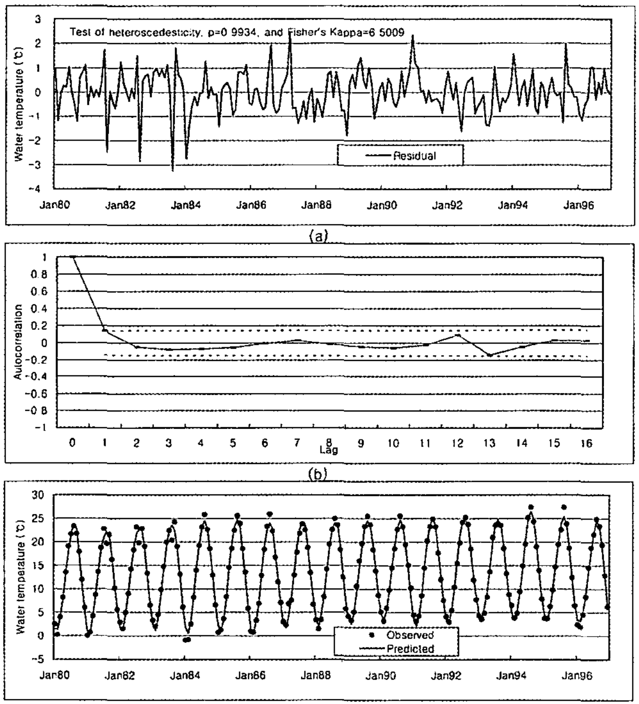

Fig. 5. Result of residual test (a) (b) and observed values and final forecasts (c). (b) is ACFs of residuals.

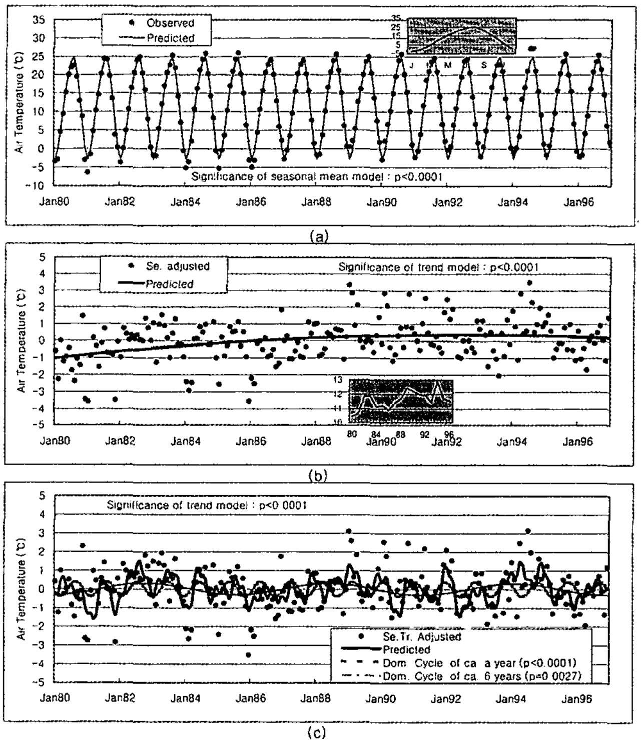

Fig. 6. Decomposition of each component from atmospheric temperature data. ((a) seasonal mean model; (b) trend model; and (c) cyclical variation model)

Table 5. Percent and cumulative percent of precipitation data variance explained by the seasonal mean, and cyclical variation model and their significance

	Sum of Squares	Percent	Cumulative Percent	R-square	F-value	Prob>F
Seasonal mean	3279407.731	72.349%	72.349%	0.7235	41.864	<0.0001
Cyclical variation	498170.264	10.990%	83.340%	0.3975	6.423	<0.0001
Error	755178.106	16.660%	100.000%			
Total	4532756.100	100.000%				

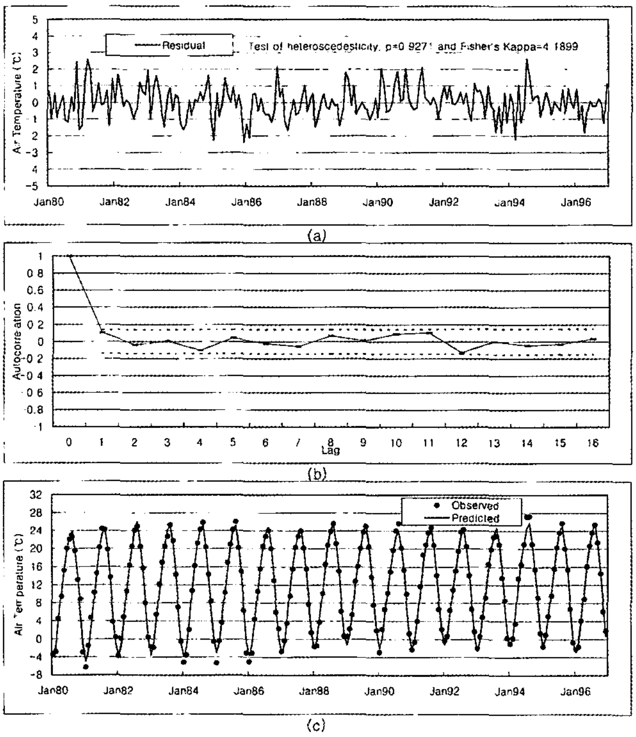

Fig. 7. Result of residual test (a)-(b) and observed values and final forecasts (c). (b) is the ACFs of residuals.

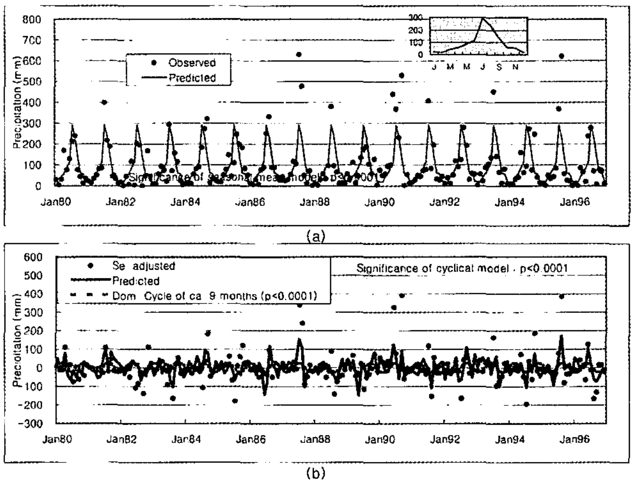

Fig. 8. Decomposition of each component from precipitation data. ((a) seasonal mean model; and (b) cyclical variation model)

precipitation of over 400 mm during the rainy seasons of 1987, 1990, 1991, 1993, and 1995, etc.).

Discussion

Temporal variations in mean sea level

Temporal variations in mean sea level have been studied by Kang and Lee (1985) and Oh et al. (1993). The studies focused mainly on the seasonal patterns because for the most part, the variation in mean sea level oscillations was explained by seasonal components. In the study, the ranges of seasonally adjusted data varied between ± 5 cm, while the seasonal variation ranged up to 40 cm. The most dominant variation is ascribed to the seasonal variation in the inverse barometric effect, steric departure and wind stress caused by monsoons (Kang and Lee, 1985).

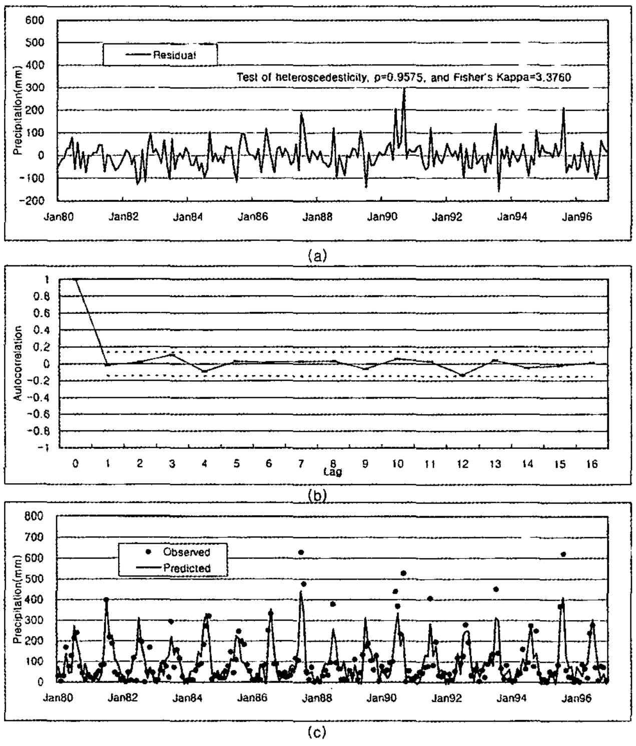

Fig. 9. Result of residual test (a)-(b) and observed values and final forecasts (c). (b) is the ACFs of residuals.

Storm surges have been found to affect the mean sea level. The surge effects, however, usually last about an hour and do not last several days except in a few cases (Lee and Oh, 1994). A ten-day duration has been observed before, thus some anomalies (*e.g.*, in late 1985 and early 1986) may be attributed to the effect of predominant monsoons or an extratropical storm at that particular time.

The trend that existed during the study period may be interpreted as being related to a partial tide with a period of 18.613 years (Schureman, 1941). This, however, may be proven by means of a harmonic analysis that entails observing the predicted values with and without the periodical components of 18.613 years. Anyway, it was found that the important component of the temporal variation in mean sea level was seasonality.

The fact that the sea level rises at a rate of 10 and 20 cm per 100 years has been recognized in the North Sea (Siefert, 1990). A significant height change in the tidal flats parallel to the rising sea level has not transpired. Instead, the tidal range has increased during the last two decades. In this study, the data were not inspected in terms of tidal range variations (*e.g.*, variation in mean high water level and low water level). Whether or not a similar phenomenon occurred in the area being examined could be estimated indirectly using the result of a harmonic analysis at NORI (National Oceanographic Research Institute in Korea). Although significant changes or trends were not detected in the area's tidal system (per. comm. with W. J. Jung), careful observation should be concentrated on this aspect in order to gain more detailed information about the likely ecological processes in this region.

Climate variations

Studies on long-term variations in sea surface temperature in the Yellow Sea and the southern waters of the East Sea were carried out by Lie et al. (1986) and Ro (1989). The studies found no increasing or decreasing trend, and this may be due to two points: (1) no trend existed in reality; and (2) concerns of temperature variation were focused mainly on spatial variation and dominant patterns in a temporal scale (*e.g.*, seasonality). So far, some of the studies discussed the warming trend or events in a certain time scale in Korea. Recently, the properties in Deep Waters in the East Sea have been changed significantly during at least the last 25 years (Kim and Kim, 1996) and it was interpreted as reflecting recent global changes such as global warming. A biological evidence was reported that zooplankton biomass has doubled from the 1960s~1980s to the 1990s (Hahn, 1998). Hahn (1997, 1998) suggested that attention should be paid to the climatic changes due to global warming and its impact on the ecological process.

This study has limitations in dealing with global changes due to the relatively short study period and locality. The authors believe that temperature rise related to global warming as triggered by increase in CO_2 would not be detected in time scales of a few decades. Many studies have dealt with climatic changes due to the greenhouse effect (De Boois, 1990; Hansen and Lebedeff, 1988; Hekstra, 1990; Jones et al., 1986). According to Hansen and Lebedeff (1988) and Jones et al. (1986), a warming trend has been found in the global mean temperature from a century ago, which has increased sharply during the last few decades. Future forecasts by some models (*e.g.*, GCMs, General Circulation Models) have indicated that the temperature will continue to increase unless greenhouse gas emissions are controlled. However, trends in temperature measured in a longer time scale are not important for ecologists, but information on the detailed fluctuating patterns in shorter time scales are necessary. This is because abnormal weather, such as a mild or severe winter and a hot summer in a year, does have a remarkable effect and can cause significant changes in biological communities. If we accumulate information and have enough knowledge on the biological variations related to these events, qualitative forecasts of a kaleidoscope of ecological processes would be possible. The abnormal patterns observed in this study (*i.e.*, successive mild winters in the 1990s) could provide invaluable information about related probable changes including the appearance of southerly species, changes in community structures, or other ecological selection processes at community levels.

Temporal variation patterns of macrobenthos assemblages in tidal flats

All the environmental variables considered here were shown to have a strong seasonality that may be a cause of the seasonal variation in macrobenthos assemblages, although segregating the effects among these variables may be difficult. Of course, seasonal variation is one of our concerns, but this is a repetitive phenomenon. Of our primary concerns are those that are related to trend and cyclical variations of more than a year. The discussion will deal mainly with the probable inter-annual variations of biological assemblages. Seasonal variations in mean sea level and precipitation would be discussed briefly.

As described earlier, the principal pattern of the macrobenthos community in the area was found to be regulated orderly by substratum properties and the tidal elevation effect. The boundaries among tripart biological zones approximately coincided with those among substratum types (*i.e.*, silt, sandy silt and silty sand). The effect of tidal elevation regarding the pool of physiological stress should not be disregarded because of the presence of an elevation-specific species group.

The estimated similarity percentage of tidal flat assemblages in the same elevation was 58% in species presence-absence data and 57% in quantitative species abundance data, respectively (Yoo et al., in prep.). It is reasonable to postulate that samples at the same level on the gradient would not be expected to have an identical species composition (Pielou, 1975). The most useful information derived from the study was that the similarities in averages changed linearly and decreased in proportion to the distance between sampling stations along the gradients. In terms of abundance, mean similarities decreased by 3%, whereas the distance between two samples on the across-the-shore transect was 100 m. Steepness of the area being examined is about 1.37/1000 and 14 cm per 100-m distance in a 4-km width from the high flat to the low flat. A vertical seasonal range of 40 cm indicates a movement of 300 m (or changes of 10%) in the monthly mean sea level on a horizontal scale. Hence, it was questioned whether macrobenthos would respond to the seasonal variability of the mean sea level. From this viewpoint, observing the spatial variation among biological assemblages (esp. in highly mobile and short-living species) is necessary.

Among the various factors regarding physiological stress in the intertidal zone, Peterson (1991) discussed the potential impact of heavy rainfall. Osmotic shock causes osmotic imbalances in and out of the body of the organisms. Intensive precipitation in summer may have a large impact on the intertidal inhabitants and may cause seasonal variations among the intertidal communities. Vernberg et al. (1974) studied salinity and temperature effects on marine organisms and maintained the importance of multiple factor interaction (*e.g.*, salinity, temperature and pollutants). Mass mortality of the principal species in this tidal flat, which occurred frequently in the early 1990s, is not an independent event by virtue of the observed patterns in temperature and precipitation.

When Gray and Christie (1983) observed temporal variations in marine benthic communities, they postulated that natural variations within sample periods could be explained by periodicities (*e.g.*, composite sine and cosine curves) which have a clear physical origin. In the suggested periodicities, 3-4 years, 6-7 years and 19 years of periodicities coincided with significant periods of this study (*e.g.*, 4, 6, and 18.6 years in mean sea level, 6 years in air and water temperatures, etc.). Based on the suggestion, even the trends in some environmental variables could be shifted into the cyclical variation domain. This was the same as in the cases of other studies (Colebrook and Taylor, 1982; Fromentin et al., 1997). Correspondence among other related studies teaches us the importance of periodicities in understanding community variations. More careful observation is needed in interpreting inter-annual variations.

As described earlier, the biological sample period used in this study falls under the successive warm periods. Important changes related to temperature variation were discussed by Beukema (1992), and Fromentin et al. (1997). After mild winters in the tidal flats of the Wadden Sea, predation pressure became more effective, survival of their prey was seriously affected and the number of species increased (Beukema, 1992). Fromentin et al. (1997) also reported that temporal discontinuities in species assemblages coincided with the alternation of mild and severe winters. In this study, however, there was no alternation, but a warm period of mild winters continued. We expected not an interrupted but a continuous variation to be detected in the communities. Not all the biological constituents, however, would respond to these changes. As Gray and Christie (1983) suggested, an assessment with the presence of opportunistic and rare species may be inappropriate due to their extreme responses in relatively short terms in the former case, and low frequencies that may cause reliability problems in the latter. Hence, a careful approach is necessary to find a suitable group of species. For further work regarding temporal variations in macrobenthos communities in the area examined, the main concern should be concentrated on whether the parallel patterns in relation to temperature prevail or not.

Acknowledgement

The authors wish to acknowledge the financial support of the Korea Research foundation to Jae-Sang Hong made in the program year of 1997 (Contract No. 1997-001-D00343).

References

Beukema, J.J., 1992. Expected changes in the Wadden Sea benthos in a warmer world: lessons from periods with mild winters. Neth. J. Sea Res., 30, 73~79.

Bong, J.H., 1978. Tidal currents in the channel near Incheon Harbour. J. Oceanol. Soc. Korea, 13, 29~34 (in Korean).

Choi, B.S., 1992. Univariate time series analysis 1. Sekyong-Sa, Korea, 736pp. (in Korean).

Colebrook, J.M. and A.H. Taylor, 1982. Significant time-scales of long-term variability in the plankton and the environment. In *Biological productivity of continental shelves of the temperate zone of the North Atlantic.* ICES Symposium, Wood's Hole March 1982 contribution 19, pp. 1~7.

De Boois, H., 1990. Ecological interpretation of climate projections. In *Expected effects of climatic change on marine coastal ecosystems,* J.J. Beukema, W.J. Wolff and J.J. W.M. Brouns, eds. Kluwer Academic Publishers, Netherlands, pp. 17~22.

Frey, R.W., J.D. Howard and J.S. Hong, 1987a. Prevalent lebensspuren on a modern macrotidal flat, Inchon, Korea: ethological and environmental significance. PALAIOS, 2, 571~593.

Frey, R.W., J.S. Hong, J.D. Howard, B.K. Park and S.J. Han, 1987b. Zonation of benthos on a macrotidal flat, Inchon, Korea. Senckenbergiana marit, 19, 295~329.

Fromentin, J.M., F. Ibanez, J.C. Dauvin, J.M. Dewarumez and B. Elkaim, 1997. Long-term changes of four macrobenthic assemblages from 1978 to 1992. J. Mar. Biol. Ass. U.K., 77, 287~310.

Gaynor, P.E. and R.C. Kirkpatrick, 1994. Introduction to time-series modelling and forecasting in business and economics. McGraw-Hill, Inc., 625pp.

Gray, J.S. and H. Christie, 1983. Predicting long-term changes in marine benthic communities. Mar. Ecol. Prog. Ser., 13, 87~94.

Hahn, S.D., 1997. Temperature variability as prime environmental change for responsible fisheries activity. In *Environmental aspects of responsible fisheries,* Proceedings of the APFIC Symposium, Seoul, Korea, pp. 21~21.

Hahn, S.D., 1998. Global warming and its effect on marine ecosystems. In *Global warming and ecosystem disturbance,* Proceedings of the V 5th environmental policy for green life, Korean federation for environmental movement, pp. 25~36.

Hansen, J. and S. Lebedeff, 1988. Global surface air temperatures: update through 1987. Geophys. Res. Lett., 15, 323.

Hekstra, G.P., 1990. Man's impact on atmosphere and climate: a global threat? Strategies to combat global warming. In *Expected effects of climatic change on marine coastal ecosystems,* J.J. Beukema, W.J. Wolff and J.J. W.M. Brouns, eds. Kluwer Academic Publishers, Netherlands, pp. 5~16.

Ibanez, F. and J.C. Dauvin, 1988. Long-term changes (1977 to 1987) in a muddy fine sand *Abra alba-Melinna palmata* community from the Western English Channel: multivariate time-series analysis. Mar. Ecol. Prog. Ser., 49, 65~81.

Jang, H.D., 1989. Changes of depositional sedimentary environment in Han River Estuary and Kyunggi Bay after the Han River's development. MS thesis of Inha Univ., Korea. 82pp. (in Korean).

Jones, P.D., T.M.L. Wigley and P.B. Wright, 1986. Global temperature variations between 1861 and 1984. Nature, 322, 430~434.

Kang, Y.Q. and B.D. Lee, 1985. On the annual variation of mean sea level along the coast of Korea. J. Oceanol. Soc. Korea, 20, 22~30.

Kim, E.J. and B.S. Choi, 1990. Primer of time series analysis using MINITAB. Jayu Academy, Korea, 338pp. (in Korean).

Kim, K.R. and K. Kim, 1996. What is happening in the East Sea (Japan Sea)?: Recent chemical observations during CREAMS 93-96. J. Kor. Soc. Oceanogr., 31, 164~172.

Koh, C.H. and H.C. Shin, 1988. Environmental characteristics and distribution of macrobenthos in a mud flat of the west coast of Korea (Yellow Sea). Neth. J. Sea Res., 22, 279~290.

KORDI, 1981. Studies on the useful fisheries resources in Garolim Bay: larval stock of the Gunnels, Enedrias species. BSPE 00030-55-3, Korean Ocean Research and Development Institute, 81pp. (in Korean).

Lee, J.K. and I.S. Oh, 1994. A study of storm surges of the seas in North Eastern Asia I. Analysis of yearly maximum surge. J. Kor. Soc. Oceanogr., 29, 28~41.

Lee, Y.H., 1987. The adaptation modes of two burrowing crabs, Helice tridens sheni and Macrophthalmus japonicus, in the intertidal mudflat. MS thesis of Seoul Nat. Univ., 58pp. (in Korean).

Lie, H.J., I.K. Bang and Y.Q. Kang, 1986. Empirical orthogonal function analysis of seawater temperature in the Southeastern Hwanghae. J. Oceanol. Soc. Korea, 21, 193~202 (in Korean).

Oh, I.S., A.B. Rabinovish, M.S. Park and R.N. Mansurov, 1993. Seasonal sea level oscillations in the East Sea (Sea of Japan). J. Oceanol. Soc. Kor., 28, 1~16.

Peterson, C.H., 1991. Intertidal zonation of marine invertebrates in sand and mud. American Scientist, 79, 236~249.

Pielou, E.C., 1975. Ecological diversity. A Wiley-Interscience Publication, 165pp.

Ro, Y.J., 1989. Interannual variability of sea water temperatures in the southern waters of the Korean East Sea. J. Oceanol. Soc. Kor., 24, 1~14.

Schureman, P., 1941. Manual of harmonic analysis and prediction of tides. U.S.C. and G.S.

Siefert, W., 1990. Sea-level changes and tidal flat characteristics. In *Expected effects of climatic change on marine coastal ecosystems*, J.J. Beukema, W.J. Wolff and J.J. W.M. Brouns, eds. Kluwer Academic Publishers, Netherlands, pp. 105~112.

Vernberg, W.B., P. J. DeCoursey and J. O'Hara, 1974. Multiple environmental factor effects on physiology and behavior of the fiddler crab, Uca pugilator. In *Pollution and physiology of marine organisms*, F.J. Vernberg and W.B. Vernberg, eds. Academic Press, New York, pp. 381~425.

Yi, S.-U., 1972. On the tides, tidal currents l prisms at Inchon Harbor. J. Oceanol. Soc. Korea, 7, 86~97 (in Korean).

Yoo, J.W., 1998. The spatial distribution and long-term variation of macrofaunal communities on macrotidal flats in the West Central Coast of Korea. Ph. D. Thesis, Inha Univ., Korea, 352pp.