Korean megatidal environments and tidal power projects : Korean tidal flats – biology, ecology and land uses by reclamations and other feasibilities

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I ■ INTRODUCTION

This paper describes the environments and biology of the Korean west coast, which is known to be one of the unique megatidal regimes. The tidal height recorded at Incheon Harbor located in the central west is larger than 10 m. Land uses of the Korean coastal area have mainly been focused on the reclamation of the tidal flats which are produced during the ebb tides. The high tidal ranges associated with the gentle sea-bottom slope create broad tidal flats along the Korean west coast. Attentions have also been paid to an use of the tidal energy provided by the strong tidal current at the mouth areas of the Garolim Bay, but the project on the tidal power plant has not been executed until today [1].

Coastal uses of the Korean west coast can be projected in various ways ; fisheries, shipping and port, reclamations, militaries and of course the tidal power plant. However, all those exploitations could then be advanced, if the consequences are not deleterious to the coastal environment. Unfortunately, the Korean newspapers carried an increasing volume of articles addressing the issues of the coastal pollution and the scientific reports also indicated impacts of the coastal deterioration on the coastal ecosystem. The degradation of an artificial saline lake « Sihwa » which was formed after a sea-wall construction in 1993 was one of the main issue of the Korean newspapers and broadcasts last summer.

The present paper was designed to examine the feasibility of the tidal power plant on the Korean coast, but efforts have been directed rather to a description of the environments and organisms on the Korean west coast, especially, the tidal flat. It was thought that understanding the ecology is already an act of the feasibility study on the coastal uses whatever it concerns. Tidal flat flora, fauna and biological productions are described with emphases on the interruptions of the coastal ecosystem observed after the intensive uses in terms of the tidal flat reclamation.

Korea is a peninsula inhabited over 4.3 million people (south) and on the road to an economic development since 1960's. Three sides of the country are bordered to the seas of the East Sea, South Sea and West Sea. The East Sea contains the deep basin formed as a back-arc basin behind the Japanese Islands. The West Sea is the eastern part of the Yellow Sea, a shallow continental shelf whose depth reaches only to about 55 m in average (maximum less than about 100 m).

Les environnements à fortes marées en Corée et les projets de centrales marémotrices

La côte ouest de la Corée connaît un régime de fortes marées. La côte est exploitée pour la pêche, les activités portuaires, militaires et la force marémotrice. Mais la construction du barrage à l'origine du lac salé Sihwa n'a pas été sans conséquences écologiques sur la faune et la flore. Or la production de bivalves est importante pour l'économie coréenne. L'installation d'une usine marémotrice pourrait contribuer à la baisse de la pollution dans le lac par des échanges d'eau plus importants avec la mer.

Coastal areas of Korea have long been exposed to an industrial use for the achievement of a rapid economic growth during the last three decades. At the initial phase of the industrialization, industrial complexes have largely been established around bays on the coast of the East Sea and South Sea, but have expanded to the coast of the West Sea since the mid 1980's. The West Sea is a region affected largely by higher tides up to 10 m. The high tidal ranges and the gentle bottom slope produce broad tidal flats which rival those on the North Sea coast. Along the coast of the West Sea, tidal flats are developed to about 10 km wide in many places and occupying an area of approximately 2 850 km^2. The coast line has a length of about 3 300 km due to the deep and dented geomorphology. The coastal use on the West Sea was directed rather to a reclamation of tidal flats by separating them from the sea by dikes. Land earning was the prime interest and, therefore, tidal flats have frequently been blocked and landfilled.

The Ministry of Agriculture estimated the aerial dimension of the coastal zone possible to reclaim as about 4 000 km^2, of which 620 km^2 (15 % of the total) is already diked by 1994. At present, an area of 760 km^2 (20 %) is under the construction of barriers, and 2 700 km^2 (65 % of the total) is planned to create lands for an industrial and agricultural purpose. If all the tidal flats reclamation projects run as planned, the coast line of the West Sea would be rounded with barriers and dikes, and the tidal flats to be remained are extremely small by the beginning of 21 century. It can easily be expected that those deteriorations of tidal flats would portend future negative effects on the coastal ecosystem.

Little attention has been paid to the biology and ecology of Korean tidal flats compared with those studies on North Sea coasts [2, 3]. Ecological concerns of tidal flat organisms to Korean coastal waters have hardly been understood due to the lacks of investigations on the tidal flat ecosystem. This study was aimed primarily to present biological data to give an overview of flora and fauna occurring on the Korean tidal flat. Biological resources were also evaluated based on data of secondary production estimated for bivalves. Statistics on fisheries catches are also included. By referring historic records of the tidal flat reclamation and warning signals on its environmental impacts already observed, we have discussed the future strategies of the human uses of the Korean coast. It was, namely, of our question how political economy and collective action concerning the utilization of such unique megatidal coast should be structured in the future.

II ■ GEOMORPHOLOGIC AND DEPOSITIONAL SETTINGS

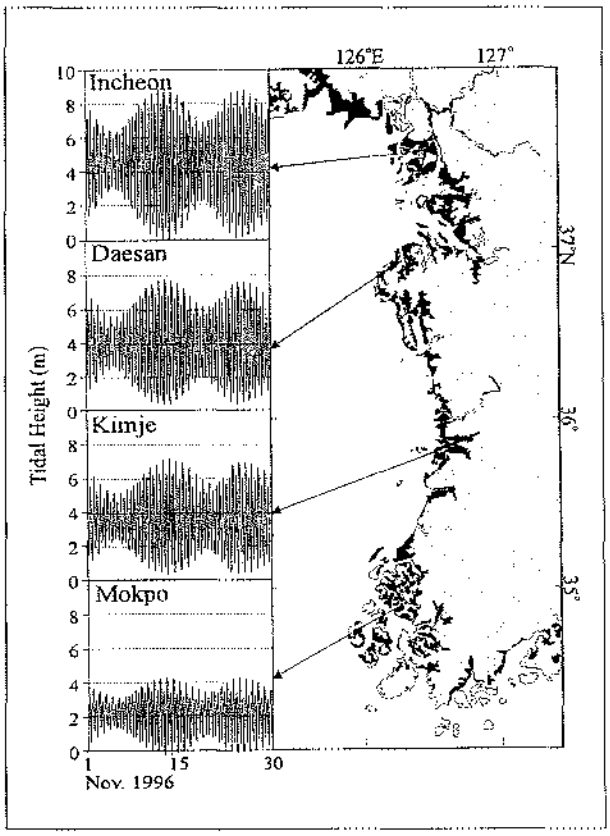
The Korean coast is one of the rias which are reported from other parts of the world, i.e., the Iberian Peninsula, Brittany in France, Deven and Cronwall in the British Isles, China and Argentina (Castaing and Guilcher, 1995). The rias of the Korean coast are mainly located on the south and west coast. The number of islands off the coast is exceptionally large (approximated to about 3 000), especially in the south, and the southwest, but also to some extent in the west. Most islands are outcrops of up to about 200 m height composed of granites and sedimentary rocks. Mountains and hills of 300 to 800 m in the south and 150 to 200 m in the west are closed to the shore line. Tidal flats are developed then from the shore line out to the sea. The channels of about to 30 m depth near the coast are mostly in the NE-SW direction in the west.

The modern tidal flats on the west coast of the Korean peninsula were formed during the recent Holocene rise of sea level. They are less than 10 000 years old. The development of Korean tidal flat is supposed to be related with the large supply of sediment from Hwanghe River and Yangze River. Sediments transported southward by currents in coastal waters off the Korean coast were calculated to be 25-250 × 10^6 m^3 yr^{-1} which was considered one or two orders of magnitude greater than discharges from Korean rivers alone [4]. Therefore, sediments on the Korean tidal flats is supposed to be derived from other parts of the Yellow Sea.

The tidal range in spring tides increases from 2.4 m in the southeast to 3.9 m in the south, 4 m in the southwest in the South Sea and 7 m in the central west and 9.3 m at Incheon in the northern west (*fig. 1*). The tidal range in the East Sea is insignificant (up to about 0.3 m). The areal dimension of tidal flats become larger directing to the north. For example, the Kyeonggi bay located in the most northern west contains tidal flats occupying an area of 1,0176.6 km^2, whereas the province of Cheon-Nam in the central west includes less areas of 218.9 km^2. It appears to be related with the tidal height which increases approaching to the north. However, the province of Cheon-Buk possesses an area of 946.7 km^2 of tidal flats. The dented and deepened coast line produces such large area of tidal flat, although the tidal range is not high as shown in the northern. The tidal flat developed around the province of Chung-Nam is 502.9 km^2.

Tidal flats in the west are mostly a wedge-shaped type when they occur around islands located near the coast (*fig. 1*). They are elongated to the southwest from the islands and fringe often to channels both to the east and west. Tidal currents which flow mostly in a NE-SW direction with ebb-dominated in respect to sediment transport could be considered as a factor prograding to the southwest from the barriers as islands scattered along the coast.

Tidal flats on the Korean coasts are generally divisible into three depositional settings based on the sediment type : mud flat, mixed flat and sand flat from upper to lower intertidal zone. A characteristic feature is that the usual high marshes bearing halophytes vegetation are rare or absent. Intensive reclamations carried out for the high rice production during Japanese occupancy destroyed the higher intertidal where the salt marshes flourished. Large reclamations which were made to produce salt by Japanese, especially in the Kyeonggi bay and in the Garolim bay, would be another reason for the absence of tidal marsh zones in the west. Mud flat faces occur, therefore, directly from the shore line. Mud flats prevail also in regions sheltered from the sea. The mixed flats are commonly found in the region outer the mud flat to the seaward. Sand flats are observed on the open coasts and lower tidal flats near the channel. Parallel lamination and small scale ripple beddings are frequently observed on the sand flat [5]. Physical sediment structure on sand flat includes wave and current lamination, flaser and plane bed lamination. Bioturbation in sediments was active rather on mud flats than on sand flats.



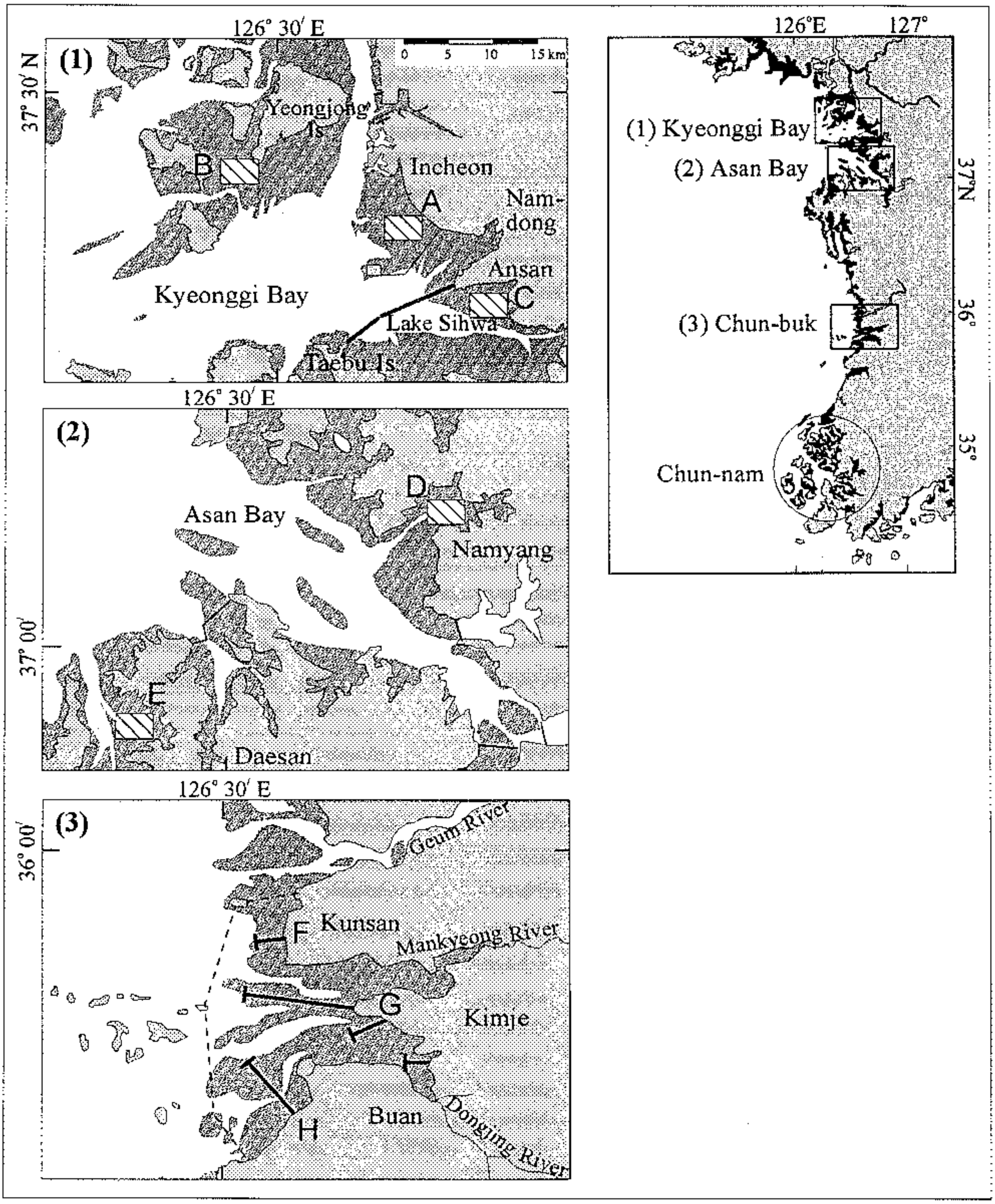
1. Areal map of the Korean tidal flat (right) with descriptions of maximum tidal height recorded along the west coast of Korea, 1988 (left).

III ■ STUDY AREA

The investigations have been conducted at 8 localities distributed along the west coast during the periods of 1984 to 1992. Study areas investigated were tidal flats on the coast of Incheon-Songdo, Yeongjongdo, Panweol, Hwasung, Daesan, Gunsan, Kimje and Buan (*fig. 2*). Followings describe the physical and sedimentological environments of those areas.

3.1 Incheon-Songdo and Yeongjongdo tidal flat

To the south-west of the city of Inchon, broad tidal flats are developed along the coast. A main tidal channel which is connected to the Han river over Kangwha Suro passes throughout this area and divides the tidal flat into two parts. Incheon-Songdo tidal flat is the tidal flat located to the east of the main channel. Sediments throughout this region consisted largely of silt and sand. The Yeongjongdo



2. Map showing the locations of tidal flats investigated (right) and detail maps describing the study area (left from top to bottom, A : Incheon-Songdo tidal flat, B : Yeongjongdo tidal flat, C : Panweol tidal flat, D : Hwasung tidal flat, E : Daesan tidal flat, F-H : Kunsan, Kimje and Buan tidal flat with transect lines set up for the investigation).

tidal flat located over the main channel differs from the Incheon-Songdo tidal flat in sediment composition. Silty to clay sediments predominate on the Yeongjongdo tidal flat.

The area belongs to a macro-tidal regime. Mean spring tides range between 8 and 9 m and mean neap tides range between 3 and 3.5 m near Incheon harbor [6]. During spring tides, current velocities at flood tides range between 0.9 and 1.8 m s^{-1} and those at ebb tides range between 1.2 and 2.3 m s^{-1}.

3.2 Panweol tidal flat

The area could be categorized as a typical mud flat located in a almost enclosed bay near Panweol. The entire intertidal sediment is classifiable as mud except the sediment in the main tidal channel which consists of sand silt. The area has semidiurnal macrotidal cycles with tidal ranges similar to those of Incheon. Tidal current velocities in the main tidal channel range between 1.1 m s^{-1} at spring tides and 0.5 m s^{-1} at neap tides [7].

3.3 Hwasung tidal flat

This tidal flat is also a typical mud flat frequently found in an embayment on the Korean coast. Sandy silts were mainly distributed in a narrow range along the channel which passes throughout the study area in a NE-SW direction. In the area, a drainage network is developed with a number of small tributary gullies. Current velocities were supposed to be similar to those observed in Panweol area. The Hwasung tidal flat is located in a deepened bay about 10 km far from Panweol to the south.

3.4 Daesan tidal flat

The area studied is one of the splays resembling a bunch of grapes developed in the Garolim bay. A tributary channel branching from the main tidal channel in the Garolim bay is extended to the outer tidal flat of the study area. Sediments around the channel consisted largely of sand, but silty sediments predominated on the inner tidal flat.

3.5 Kunsan, Kimje and Buan tidal flat

These tidal flats are located side by side each other from the city of Kunsan to Buan in a N-S direction. The whole region is commonly called Saemankeum Area due to a large reclamation project launched in 1993. All the tidal flats around this area is to be diked till around the year of 2000. The tidal flats studied are the broadest ones in the west. The intertidal zone is 20 km broad at the central area and has an area of approximately 170 km^2 when estimated at the lowest low water. The Kunsan tidal flat receives the flow of the Mangyung river which joins with the main channel. The Dongjin river flows to the Kimje tidal flat, however, freshwater discharge was sufficiently small so than year round salinities approximated those characteristics of the offshore region. The geomorphology of these estuaries is similar to that of Keum estuary 15 km far to north which is known to a ria-type estuary dominated by tides [8, 9]. The inner tidal flat of the study area was located within the mouth of the two rivers where the fine grained sediments predominated. Sediments on the outer flats were coarser, mainly sand.

The bathymetry is reflected in the flow patterns of tidal currents which dominated over the whole tidal flat. Major flood and ebb currents were in a NE-SW direction offshore. Tides are mixed semidiurnal, with a mean tidal range of 4.3 m, a maximum spring tidal range of 6 m and a minimum neap tidal range of 3 m. Current velocities range between 0.8 and 1.8 m s^{-1} at flood tides and between 1.2 and 2.4 m s^{-1} at ebb tides [10].

IV ■ MATERIALS AND METHODS

4.1 Sampling and Estimation of Annual Production

4.1.1 Benthic diatoms

Object organisms for the study of flora were restricted rather to benthic diatoms than other micro-organisms as Cyanobacteria and halophytes. Sediment samples were taken from four tidal flats of Incheon-Songdo, Kunsan, Kimje and Buan. The flora on the Incheon Songdo tidal flat was investigated by samples collected from three sites during June of 1987. Samplings on the other three tidal flats were carried out during June 1988. Twelve sampling sites on the Kunsan tidal flat were selected. The number of sampling sites at Kimje was 29. Sixteen sites were chosen at Buan. All the site for the floral investigation was set up on the transect lines running perpendicular to the shore.

About 100 g of surface sediments were collected at each site by a plastic core 30 mm in diameter. In order to observe the frustle structure of diatoms for identification purposes, the sediment samples were treated with hydrochloric acid. Diatom cells were eluted from sediment samples by passive settling and repeated washing [11]. Subsamples of the elutant were mounted in Hyrax and the permanent slides were used for both identification and counting of diatom taxa. Abundance (number of diatoms per cm^{-2}) was calculated by multiplying the number of cells of a taxon by the dilution factor and adjusting this value to the actual area of the sample core.

4.1.2 Tidal flat invertebrates

Occurrence of the tidal flat animal was investigated at 8 localities listed above. A box core of 0.1 × 0.2 × 0.3 m (surface area : 0.02 m^2) was mostly used to collect the benthic animal. On the Incheon-Songdo tidal flat, five box core samples were taken from two transect lines starting from Songdo and Dongmak in April 1991. The collected sediments were washed on a 1 mm mesh sized sieve, and the animals retained were fixed with 10 % formalin solution in seawater. The samples on the Yeongjongdo tidal flat located to the west of the Incheon-Songdo tidal flat was collected from 20 stations in 1989. Thirty stations on the Panweol tidal flat were investigated in September 1984, but the animal was collected directly by hand, not by a box corer, while the sediment was dug down to 50 cm depth within two 1 × 0.5 m quadrats at each station. The fauna on the Hwasung tidal flat was studied at 16 stations in July 1992. Samplings on the Daesan tidal flat were carried out at 26 stations during July 1993. The locality and investigation period of the faunal study on the Kunsan, Kimje and Buan tidal flats were the same as those of the floral study and the animal was collected by hand digging the sediment down to 50 cm depth. Two of 0.5 × 0.5 m quadrats were sampled at each station. After identification and counting the individuals, all the values on individual numbers were converted to the numbers per m^2.

4.1.3 Measurement of the primary production of benthic microalgae

Primary production of benthic microalgae was measured using the ^{14}C method at 9 occasions from March to December 1989 on the Incheon-Songdo tidal flat. In situ experiments were carried out on the exposed tidal flat at low tide. Top 5 mm of surface sediments was collected and transferred to glass tubes for the incubation. The tubes were filled with 5 ml filtered seawater from the same locality, to which about 1-2 µCi $NaH^{14}CO_3$ was added. The tubes were then incubated during midday for 1-2 h without stirring. Light grades were regulated to be 0 to 100 % of full sun by mesh screens. Photosynthetic responses to light intensities over season could therefore be obtained. The assimilated ^{14}C after the incubation was measured by liquid scintillating counter after solvent treatments.

The photosynthesis-irradiance (*P-I*) relationships over season were employed to estimate the annual primary production [12]. We calculated firstly the daily production varying with light intensity. The daily production was computed by hourly rate of production multiplied by the mean biomass (Chl-a content of the sediment) and the duration of exposure. The summation of daily production estimated under different light intensity, Chl-a content in sediments produced the annual production.

Chlorophyll contents of sediments were measured using 90 % acetone extracts with surface sediments collected from the same locality. A total of 25 samples were taken at every survey to avoid sampling bias due to any differences in chlorophyll concentration of the sample sediments. The chlorophyll content per unit area was then compared with the primary production in respect of *P/B* ratio.

4.1.4 Estimation of secondary production of bivalves

Secondary production of bivalves occurring on the tidal flat was estimated by Ricker's model ($P = GxB$). Objects organisms studied were *Mactra veneriformis* which was common to the sand flat, and *Sinonovacula constricta*, a typical bivalve on the mud flat, and *Ruditapes philippinarum* frequently found on silty to sandy sediments.

The production study of *M. veneriformis* was conducted on the Incheon-Songdo tidal flat on 17 occasions from March 1989 to September 1990. The bivalve *M. veneriformis* was collected from ten 0.5 × 0.5 quadrats randomly laid on the lower intertidal. The shell length of more than 100 individuals was measured at every survey. The flesh weight of about 30 individuals were measured after drying in an oven at 60 °C for about 3 days until the weight stayed constant. The shell length was then converted to the dry weight on the bases of regression lines between the length and the dry weight ($W = a L^b$) determined at every survey. A multiplication of the individual dry weight with individual numbers counted from the sample quadrats produced the biomass (B) which was applied to an estimation of the secondary production. The production, P, was then calculated by a multiplication of the relative growth rate, G, with the biomass [13]. The production was estimated for every age class obtained by counting the growth ring. The annual yield of *M. veneriformis* was the sum of the production calculated for every age class.

The study on the production of *S. constricta* was carried out on the Hwasung mud flat for one year from September 1992. The sample quadrat of 1 × 1 m was larger than that applied for *M. veneriformis*, because of the lower density of *S. constricta*. Measurement of the size of the object animal collected at monthly intervals was performed in a similar way to *M. veneriformis*. The estimation of the annual production was following the Ricker's model.

The production biology of the Manila clam, *R. phillipinarum*, was studied on the Daesan tidal flat on 13 occasions from 1991 to 1992. The clams were collected from nearly ten quadrats of 0.5 × 0.5 m by digging to a depth of 10 cm in every month. After the measurement of the size, the biomass and production were estimated by following the procedure mentioned above.

4.2 Estimation of areal dimension of historic reclamations

Historical records of the tidal flat reclamation appeared in the literature were surveyed for the period from the beginning of this century to present and those records were compared with maps. Changes in shore lines during these decades could therefore be followed and drawn on the marine chart. Statistics on the areal dimension of the reclamation surveyed from the literature are then given in *table 4*.

V ■ RESULTS

5.1 Type of sediment

Sediments are thought to be the major factor which determine the areal distribution of tidal flat animals. We have used the sedimentary nomenclature suggested by Shepard [14] to describe the amounts of sand, silt and clay, as determined by mechanical analysis, although benthic ecologists are not fully agreed with what sedimentary parameter is most important in influencing animal distribution and what constitutes sedimentary parameters. *Figure 3* is a plot of 167 stations on triangular diagrams by the percentage of sand, silt and clay. A significant feature of *figure 3* was the predominance of sand and silty sand sediments of the Incheon-Songdo tidal flat, while the finer silts were typical of the Yeonjongdo tidal flat. The two tidal flats of Panweol and Hwasung were also distinguished by sediment composition. The majority of the Hwasung tidal flat was characterized by silts, whereas the sediments on Panweol tidal flats contained higher percentage of clay. The broadest tidal flat around Kunsan, Kimje and Buan were composed of sand to silt sediments. In brief, the tidal flat of Yeongjongdo, Panweol and Hwasung belonged to silt-mud flat, while Incheon-Songdo, Kunsan, Kimje and Buan tidal flats could be described as sandy-silt to sand flat. Among the total of 167 stations, silty sand (23.6 %), sandy silt (24.2 %) and silt faces (23.6 %) were predominated and then the sand face (15.8) followed. Less mud faces were found (7.3 %). Most stations were characterized by well sorted sediment as observed form plots along the axis of silt to sand in triangular diagrams, but several stations showing a mixture of mud with sand near Kunsan (5.5 %) were found.

5.2 Occurrence of Diatoms

Arguments on the correctness of the identification would be arisen when we treat such tiny organisms as diatoms and, especially, when we identify them under the light-microscope. Although we employed the procedure of acid washing to exclude the protoplasm in the cell and attached debris on the surface of the frustule, a large number of tiny specimens belonging to, i.e., *Navicula* and *Nitzschia* could not be identified to the species level. Though those difficulties in the identification, a total of around 120 taxa were identified (*tabl. 1*). The number of taxa remained for a further identification was counted to about 140. Those unidentified species belonged mainly to the genera *Amphora, Navicula, Nitzschia* and *Cocconeis*. The identified species from the four tidal flats investigated were represented by 42 genera belonging to 11 families. The families Naviculaceae, Nitzschiaceae, Diatomaceae in the Pennales accounted for about 70 % of the identified 120 taxa. In the Centrales, the family Thalassiosiraceae involved 9 species. Of the 42 genera encountered, *Navicula, Paralia, Amphora* and *Nitzschia* were the most dominant genera in terms of frequency and abundance. The single most abundant species was *Paralia sulcata*, which is considered as a tychopelagic species in the Korean waters. In the water samples from off Kunsan area, more than 10% of the total cell counts was attributed to *P. sulcata* (Shim *et al.*, 1991). The species of *Navicula arenaria, Cymatosira belgica, Amphora coffeaeformis, A. holsatica, Achnanthes hauckiana*, and *Raphoneis amphiceros* was then followed as the dominant group.

The Incheon-Songdo tidal flat was represented by the lowest number of diatom taxa of 51 among the localities investigated. The total number of species counted on the other tidal flats was nearly two-folds higher than that found at Incheon-Songdo. Ninety-one taxa were identified from sediment samples from Kunsan, 94 from Kimje and 97 from Buan.

The species composition differed according to the sediment faces. Sets of species were found from silt to sand faces. The dominant species on silt and sandy silt faces were *Paralis sulcata, Navicula arenaria, Cymatosira belgica, Raphoneis amphiceros, Thalassionema nitzschioides, Cyclotella atomus, C. striata, Navicula cancellata, Nitzschia lorenziana, Psammodiscus nitidus, Thalassiosira anguste-lineata, Plagiogramma vanheurckii* and *Rhaphoneis nitida*. Followings were characteristic on silty sand and sandy sediments : *Achnanthes hauckiana, Dimeregramma minor, Opephra martyi, O. marina, Cocconeis pelta, Amphora angusta* and *A. libyca*.

There was a group of species composed of those found at almost every sediment types. *Amphora holsatica* and *A. coffeaeformis* belonged to this assemblage. Other species such as *Amphora turgida* and *Navicula forcipata* could be considered as taxa without preference on the size of sediment grains, however, the abundance was low.

The abundance of most dominant species on fine grained sediments, i.e., *Paralis sulcata* and *Navicula arenaria* was much higher than those of *Achnanthes hauckiana* and *Dimeregramma minor* attached on sand grains. The total cell count of *Paralia sulcata* reached to about 60×10^4 per cm^2 on the mean grain size of 6.0 phi sediment, whereas the abundance of *Achnanthes hauckiana* was about 8×10^4 per cm^2 on the 3.0 phi sediment.

5.3 Occurrence of Tidal Flat Invertebrates

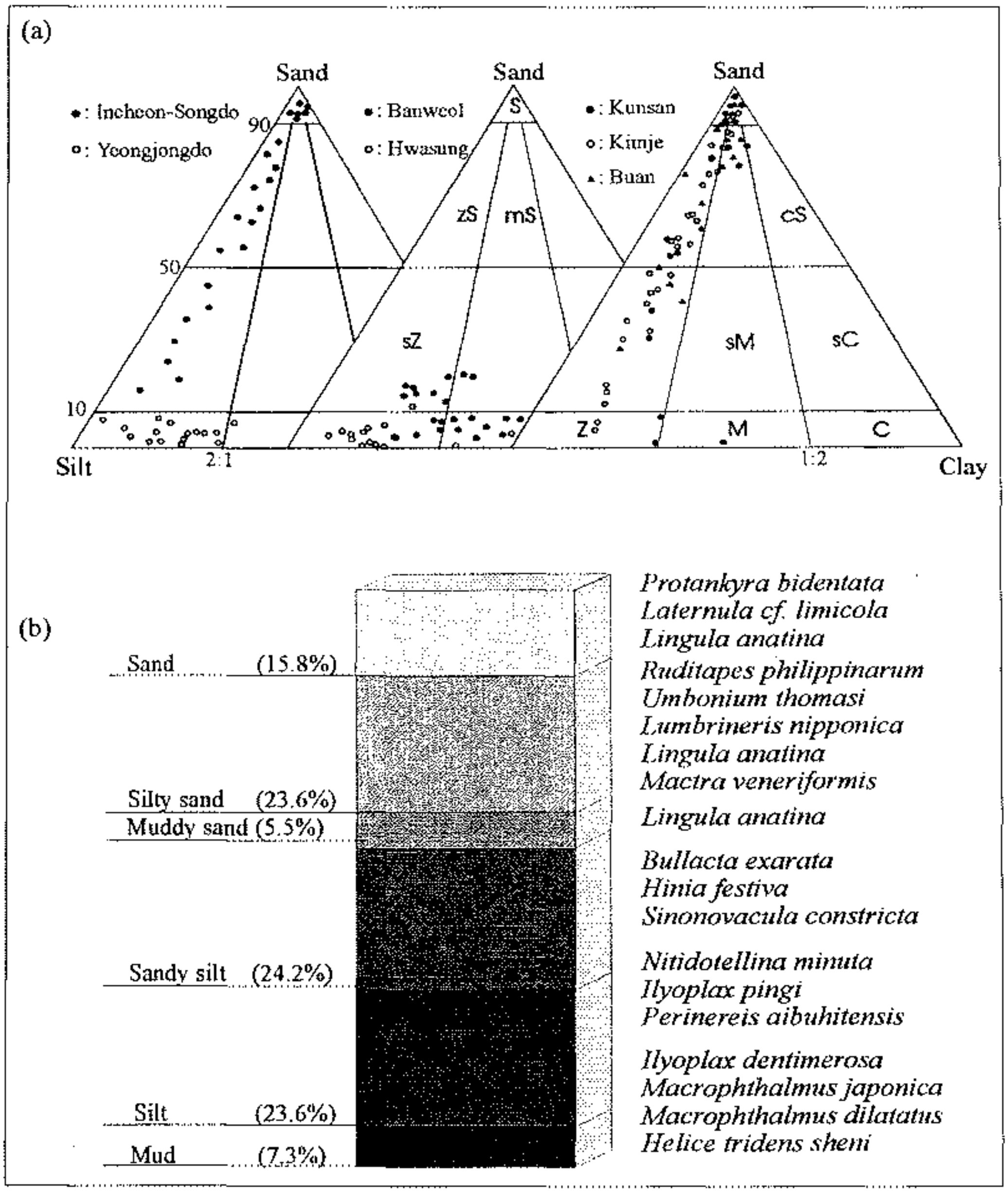
A total of 94 taxa have been collected from 167 stations spreaded over 8 tidal flats on the west coast of Korea. The polychaete involved the largest number of taxa (50 among 94 species) and then the pelecypod (16 species), crabs (12 species) and gastropod (7 species). Two of holothurian species were found : one of which *Protankyra bidentata* was considered for typical of the outer tidal flat. It would also be worth to note that the living fossil species belonging to the brachiopod, *Lingula anatina*, was found overall on the coast, but mostly near Kimje, especially in the middle intertidal in so far as the sediment was a mixed type of silt with mud.

Over 25 % of the total stations investigated showed an occurrence of 2-4 and 4 6 taxon per m^2. The number of species per m^2 (12 species) would be biased from an actual observation because of the areal coverage of the sampling carried out often by a box corer of 0.02 m^2 whose dimension was far less than 1 m^2. The accuracy in number of species would also be an argument for the samples collected by hand after digging the sediment with a spade, although the aerial coverage of samplings was exceeded over a square meter, because the sediment collected in a quadrat was not sieved to collect animals larger than a certain mesh size. However, it was impossible to execute a sieving of sediments from a large number of stations as set up in the present study. The number of species collected in the present study would, therefore, be thought for a least estimate. In spite of those shortages in collections, an overview of the number of taxon and also the number of individuals per m^2 could be obtained.

From 80 to 160 individuals per m^2 was mostly found : the number of stations fell into these categories were 55 among the total of 167 stations. The density of 40 to 80 and 160 to 320 were also frequently observed. The mean density was 1,067 individuals per m^2 with a standard deviation of 4,536. The highest mean density of 3,783 was found on the Kunsan tidal flat, however, it must be noticed that the bivalve *Laternula* cf. *limicola* occupied 98 % of the total mean. The Daesan tidal flat ranked the second in abundance (mean density of 2,648), but the density of the polychaete *Heteromastus* sp. was remarkably high (nearly 90 % of the total mean). The highly dominated species was also found on the Buan tidal flat where the mean density (1,018 individuals per m^2) was recorded as the third among the tidal flat investigated. The area was populated by epibenthic gastropod *Umbonium thomasi* was populated with high occupancy.

Data on density (individual numbers per m^2) and frequency (% occurrence at sampling stations) of the most abundant 19 taxa on 8 tidal flats are presented in *table 2*. The taxa listed in *table 2* belonged mostly to infauna. Occurrence of epifauna would be poorly described by samplings with a box core covering an area of 0.02 m^2 employed in this study. The most dominant species listed in *table* 2 would, therefore, give a different perception from that obtained when we observe the tidal flat at a glance. For example, the gastropods such as *Bullacta exarata* and *Hinia festiva* were frequently found with naked eye on the silty sediments, however, those taxa ranked second dominant group in *table 2*. In spite of those shortages, we could define characteristic species at different localities and sediment faces. Followings describe the characteristic species of each tidal flat from north to south.

The first set of 11 species in *table 2* could be considered typical of the stations on the Incheon-Songdo tidal flat. The most dominant species was the holothurian species *Protankyra bidentata* which



3. Sediments composition of stations surveyed plotted on Folk's triangular diagram (top) and representative animals at different sediment types are presented (bottom).

occurred largely in sandy sediment of the outer tidal flat. Examination of the list of species from the Yeongjongdo tidal flat revealed that the taxa were more characteristic of the silty to muddy sediments. *Nitidotellina minuta* which ranked the second in abundance is a typical bivalve frequently found around Korean coasts where the sediment is composed of silt-sized grains. It is noteworthy that the Yeongjongdo tidal flat belonged to a typical silt-mud flat as Panweol and Hwasung, but the fauna was very different from those as shown in *table 2*.

Eleven species are listed as characteristic of the Panweol tidal flat, among them the pelecypod, *Potamocorbula amurensis*, ranked the first dominant. However, the Panweol tidal flat is a shore located in the inner-most area of a tidal inlet and the burrows and the sediment mounds of crabs constituted the conspicuous surface structures of the tidal flat. Crabs such as *Helice tridens sheni* and *Macrophthalmus japonicus* were typical of the mud flat zone. The small crabs, *Ilyoplax dentimerosa* and *I. pingi*, whose carapace length is less than 1 cm were dominant in terms of abundance, but most crabs wandering around and to be seen because of the active behavior were the larger-sized crabs as *H. tridens sheni* and *M. japonicus*. The bivalve *P. amurensis* was mostly found in the channel sediment and, therefore, not conspicuous to the observer. It is also worth to note that the occurrence of the large-sized polychaete, *Periserrula leucophryna*, could be reported. The largest specimen described by

Table 1. – Occurrence of diatoms observed in surface sediments on the Incheon-Songdo tidal flat during June of 1988 and on the Kunsan, Kimje and Buan tidal flat during June of 1989. Abundance of diatoms are arbitrarily categorized into 6 grades from 1 to 5 according the frequency and cell counts. The mark of + means a minor occurrence.

Species name	Incheon	Kunsan	Kimje	Buan
Centrales				
Family Thalassiosiraceae				
Cyclotella atomus		3	-	+
C. comta	+	+	-	+
C. meneghiniana	+	1		+
C. striata	4	2	1	-
Cyclotella spp.			+	
Stephanodiscus sp.		4	+	-
Thalassiosira eccentrica	3	1	+	+
T. leptopus	1			
Triblioptychus cocconeiformis	1	+	+	
Family Melosiraceae				
Hyalodiscus radiatus	+	+	-	
H. scoticus		+	-	
Melosira granulata			-	
Paralia ornata			+	
P. sulcata	5	5	5	3
Family coscinodiscaceae				
Coscinodiscus anguste-lineatus	4	2	+	+
C. nitidus		3	+	+
C. marginatus	+			
C. obscrus	+			
C. plicatus	+	1	+	+
Coscinodiscus spp.		+	-	+
Family Hemidiscaceae				
Actinocyclus ehrenbergii		+	+	+
Family Heliopeltaceae				
Actinoptychus senarius		-	+	+
A. splendens		+	+	+
Family Biddulphiaceae				
Biddulphia aurita	+	+	+	+
Cymatosira belgica	4	4	3	3
Eucampia zodiacus	+	+		
Pennales				
Family Diatomaceae				
Dimeregramma minor		+		1
D. minor var. *nana*		+		+
Fragilaria brevistriata			+	-
F. pinnata			+	-
F. virescens var. *oblongella*		+	+	+
Fragilaria sp.				1
Licmophora sp.			+	-
Opephora marina				+
O. martyi				1
O. schwartzii			+	
Plagiogramma vanheurckii	2	2	+	+
Rhaphoneis amphiceros	2	3	2	1
R. nitida	2	2	1	+
R. surirella	4	2	1	+
Synedra tabulata	-		+	+
Synedra spp.		2	+	+
*Thalassionema nitzschioides*1	4	3	+	
Family Eunotiaceae				
Eunotia faba var. *obtusa*		+	+	+
Eunotia sp.			+	+
Family Achnanthaceae				
Achnanthes delicatual			+	+
A. dilopunctata		+		+
A. hauckiana		2	2	3
A. lanceolata var. *rostrata*		+	+	
Achnanthes sp.		1	1	1
Cocconeis grata		+		+
C. pelta				+
C. scutellum var. *pava*	+	+		+
Cocconeis spp.				1
Family Naviculaceae				
Amphipora alata		+	+	+

Species name	Incheon	Kunsan	Kimje	Buan
Amphora angusta	+	+		1
A. coffeaeformis	1	4	3	3
A. graeffeana		+	+	+
A. holsatica		2	4	2
A. laevis	+	+		+
A. libyca		2	+	2
A. montana		+		+
A. pediculus		+		+
A. proteus	-	+		1
A. sabyii			+	1
A. turgida	+	2	+	+
Amphora spp.		1	1	1
Caloneis brevis var. *distoma*		+	+	+
C. affinis		+	+	+
Cymbella ventricosa	+	-	+	+
Diplneis smithii		+	+	+
Diploneis weissfolgii	+	1	2	1
Donkinia recta		-	+	
Frustulia interposita		+	+	
Gomphonema parvulum		+	+	+
Gyrosigma balticum	+	+		+
G. obtusatum	-			
G. scalproides	3	+		+
G. spencerii	1	1	1	1
Navicula arenaria	5	4	5	1
N. cancellata		+	1	+
N. contenta				1
N. cryptocephala	4	1	1	1
N. forcipata	+	1	1	1
N. giffeniana		+	+	-
N. gregaria		+	1	+
N. insignita		-	+	1
N. jaernefeltii		+	1	
N. protracta		+		+
N. salinarum	-	1	1	-
N. scopulorum	2		+	+
N. subforcipata		+	+	+
Navicula spp.	3	4	4	4
Pinnularia ambigua	3	3	+	+
Pinnularia spp.	1	1	1	1
Pleurosigma angulatum		+	+	+
P. normanii		+	+	
Stauroneis dubitabilis		2	2	
Trachyneis aspera	+	1	1	+
Tropidoneis lepidoptera		+	-	+
Family Nitzschiaceae				
Hantzschia virgata		+	+	
Nitzschia amphibia		-	+	1
N. dissipata		+	+	+
N. fonticola	1	2	1	+
N. granulata	+	+	+	+
N. kuetzingiana		1	2	2
N. littoralis	+	+	+	
N. lorenziana		1	2	+
N. panduriformis			+	+
N. pellucia		1	1	1
N. punctata var. *minor*	1		+	+
N. sigma	+		+	+
N. socialis	1	1	1	+
N. spatulata		1	1	+
N. triblionella		+	-	+
Nitzschia spp.	2	2	2	2
Surirella flumnensis	+	+	2	1
S. gemma	+		1	+
S. minuta			1	
S. ovata			1	

Table 2. – Densities (D : individuals per m²) and frequencies in parenthesis (F : % occurrence among total stations (*n*) investigated) of dominant invertebrates found on eight tidal flats of the Korean coast.

Taxon		Songho	Youngjongdo	Banweol	Hwasung	Daesan	Kunsan	Kimje	Buan
		D (F : %) (*n* = 23)	D (F : %) (*n* = 16)	D (F : %) (*n* = 22)	D (F : %) (*n* = 16)	D (F : %) (*n* = 23)	D (F : %) (*n* = 17)	D (F : %) (*n* = 31)	D (F : %) (*n* = 19)
Heteromastus sp.	P	+	5 (56)		33 (63)	2 209 (100)	3 (41)	2 (10)	4 (41)
Imionium tiosmas	G	7 (13)				335 (13)	2 (24)	27 (55)	929 (82)
Lingula anatina	Br					4 (9)	45 (71)	34 (81)	20 (88)
Protakyra identata	H	115 (70)					4 (18)	3 (35)	
Mactra veneriformis	P	13 (48)					(6)	14 (48)	+
Lumiriner sinipponica	P								
Neptitys polyirancia	P				(13)	57 (35)			
Laternula cf. *limicola*	B						3 256 (24)	130 (6)	10 (12)
Potamocoriula amurensis	B			1 066 (18)			(6)	(3)	
Sinonovacula constricta	B		+	+	59 (13)				
Magelona japonica	P		245 (44)		8 (19)	+			
Ilyoplax dentimerosa	D		2 (6)	66 (59)	11 (69)		+	+	
Nepitys californiensis	P		50 (88)						
Nitidotellinaiminuta	B		221 (63)						
Perinereisiaiuituns	P		3 (6)	8 (68)	16 (56)		2 (12)	2 (16)	17 (18)
Ilyoplaxiping	D		7 (25)	22 (45)	26 (69)		6 (51)	+	2 (24)
Mediomastus sp.	P		9 (50)		13 (56)	43 (43)			
Bullacta exarata	G	27 (5)	36 (81)	+		225 (13)	5 (41)	6 (55)	4 (29)
Hinaiafestiva	G	22 (39)	7 (56)	+			+	6 (29)	13 (65)

Paik (1977) was 56 cm long and 1.3 cm wide. The bell-shaped sediment mounds on the middle intertidal belonged to this polychaete.

Fauna on the Hwasung tidal flat located about 10 km close to the south of Panweol was characterized by the dominance of bivalve *Sinonovacula constricta* which have long been used for human food in Korea. The predominance of crabs was similar to the Panweol tidal flat. The polychaete *Perinereis aibuhitensis* which ranked the fifth in abundance is a worm used for bait by angler. Most catches have been exported to Japan.

The Daesan tidal flat was represented by diverse fauna due to the diverse sediment types. This tidal flat was an area of strongest current flow characterized by a heterogeneous mixture of mostly poorly sorted sediments. Large ripples, gullies and channel are well developed. Predominant current flow is from Asan Bay into Garolim Bay, which is reflected in the derivation of many of the tidal flat organisms. The predominance of the polychaete, *Heteromastus* sp. which was mostly found in fine sediments around Korean waters, was unique for the silty to sandy faces near the channel of the Daesan tidal flat. The gastropod *Umbonium thomasi* was typical of the outer flat.

The Kunsan, Kimje and Buan tidal flat produced the largest number of species in unique combination for this habitat. The highest occurrence of the bivalve *Laternula* cf. *limicola* on the Kunsan tidal flat was due to the center of abundance near the channel connected to the Mangyung River. This taxon ranked also the first in abundance on the Kimje tidal flat, but the distribution was limited to stations located on the slope edge of the channel leading into the Dongjin River. The occurrence of a lingulid brachiopod *Lingula anatina* which has ranked the second in abundance on the Kunsan, Kimje and Buan tidal flat was highly interesting for this animal was hardly found as a living species on the world coasts. The predominance of *Umbonium thomasi* in sandy to silty bottom was observed as shown on the Daesan tidal flat. The bivalve *Mactra veneriformis* which has ranked the fourth on the Kimje tidal flat is a representative species for cultivation on the Korean tidal flat. Spats collected near the channel have been spreaded over the cultivation ground by the fishermen in late spring. The crabs and polychaetes were recorded as dominant on Kunsan, Kimje and Buan tidal flat as dominant, especially in the tidal inlet and on the upper intertidal if it faced to the open sea.

Comparisons have been made between faunal composition and sediment faces. Assigning the dominant taxa at 167 stations into sediment faces from sand to silt and clay, we could define typical taxa of every sediment type. Typical animals are then listed on every sediment type schematically *(fig. 3)*.

The sand faces were characterized by *Umbonium thomasi* accompanied with *Protankyra bidentata*. The brachiopod *Lingula anatina* extended its distribution into the silty sand and muddy sand flat. The bivalve *Mactra veneriformis* was considered as typical of muddy sand faces, however it occurred broadly also on silty sand flat. Sandy silt sediment was populated by the epifauna *Bullacta exarata*, but the polychaete *Nephtys polybranchia* was comparatively rich in the sandy silt sediment without any preference of the locality. The razor clam *Sinonovacula constricta* was mostly present on the Hwasung tidal flat. *Nitidotellina minuta* counted as typical bivalve of silty sediment, but this species was confined to the Yeongjongdo tidal flat. Mud faces were found at 7.3 % among 167 stations, however, the fauna was rich and diverse : crabs as *Helice* and *Macrophthalmus* were conspicuous over the whole Korean tidal flat. The small crab *Ilyoplax dentimeros* is listed as typical, because of the highest counts in core samples.

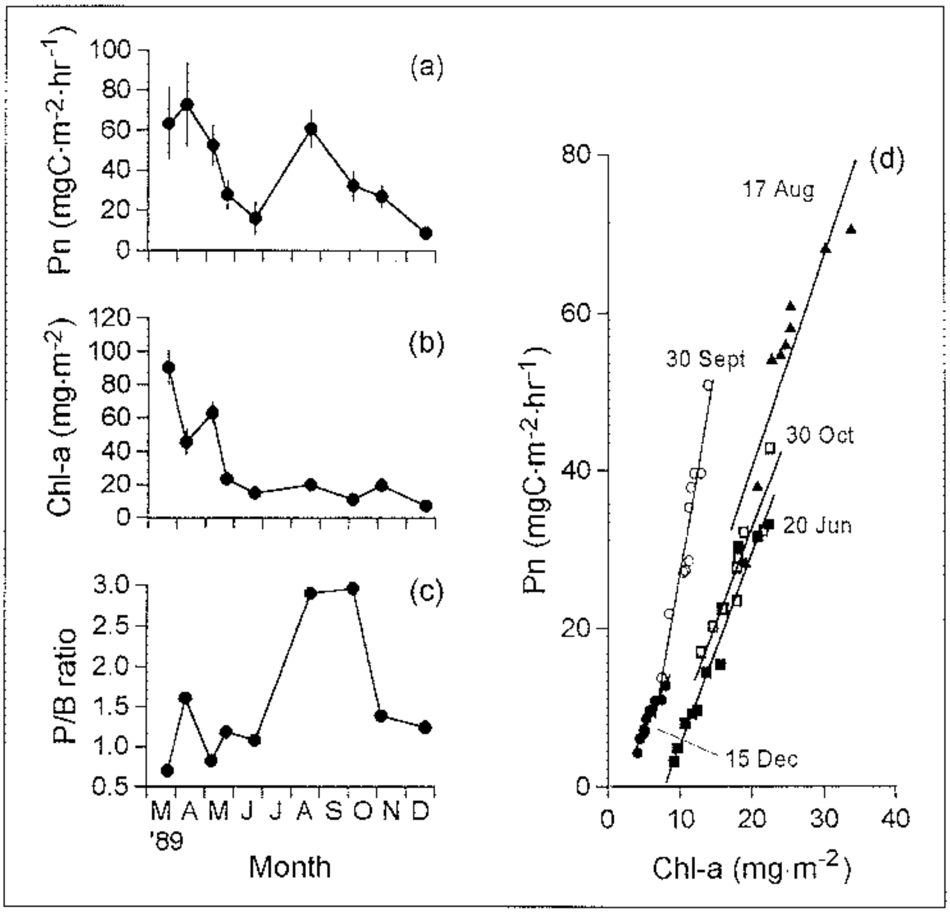
The zonation from the upper to lower intertidal could be described : crabs *Helice* and *Macrophthalmus*, the gastropod *Bullacta exarata*, the brachiopod *Lingula anatina*, the clam *Mactra veneriformis* and the gastropod *Umbonium thomasi* occurred proceeding down to the sea.

5.4 Primary Production of Benthic Microalgae

Seasonal changes in the net primary production (mg C mg chl-a^{-1} hr^{-1}) of benthic microalgae on the Incheon-Songdo tidal flat are depicted in *figure 4*. In every season, the primary production at different light intensities could be obtained by shielding the incubation tubes with nylon screens of various densities. From the experiment, means of the primary production were obtained with ten incubation tubes at every survey. The mean of the primary production divided by the mean of Chl-a content of 25 sediment samples produced the values plotted in *figure 4*.

Although not drawn in a figure, photosynthesis showed basically a hyperbola-shaped response to light intensity throughout the year. Photoinhibition was not observed at full exposure to sun light even during summer. The highest photosynthetic maximum (P_{max}) was recorded in August. The next highest values were found in September.

The P_{max} in April is about the half of that measured in August, when the estimate is presented on the Chl-a basis, but the production calculated per unit area was highest rather in April than in August. The values of primary production per unit area shown in *figure 4* are the estimates obtained at full sun light without shielding the incubation chamber. Two peaks were found in April and August. The primary production per unit area was generally high during spring (March to May) and summer (August). However, the sediment samples of August contained less Chl-a. The higher contents of Chl-a were found rather in spring. The primary production per unit Chl-a content is plotted in terms of the *P/B* ratio in *figure 4*. The highest peak of the *P/B* ratio recorded in August corresponded also with the highest P_{max}.



4. Annual changes in primary production measured without shielding the experimental chamber (a), the contents of chl-a in sediment (b) and the P/B ratio (c). The values of the ten measurements of primary production without shielding are plotted against Chl-a for every survey (d).

The relationship between the primary production and the content of Chl-a over season is demonstrated in *figure 4d*. Ten pairs of sediment samples were collected and one among the pair sample was used for the incubation and the other one was used for the determination of the Chl-a content. It was supposed that the content of Chl-a in the incubation tube was identical with that reserved for the analysis of the Chl-a content. Two plastic syringes of 12 mm diameter were put side by side into the sediment to avoid the sampling bias in terms of the pigment content. The primary production plotted in *figure 5* is the values obtained without shielding the incubation tubes. Comparison of the primary production over season would be made for a given value of Chl-a, for example, 20 mg Chl-a per m^{-2} : the primary production at 20 mg Chl-a m^{-2} in August was 42 mg m^{-2} hr^{-1} and that in June was 28 mg m^{-2} hr^{-1}. We observed the highest production in September. The content of Chl-a which produced 42 mg Chl-a m^{-2} hr^{-1} was less in September, namely, 12 mg Chl-a m^{-2}, than in August. It indicates that the efficiency of carbon incorporation by benthic diatoms was highest in September.

The exposure duration of the investigated site to the sun light was obtained by combining data on the hourly record of the tidal height at Incheon harbor *(fig. 5)* and the elevation of the site where the primary production was measured. The study site was exposed around 4 hours during the day time. Solar insolation measured at the Meteor-station Incheon was highest in summer and lowest in winter, however, the insolation reached to the tidal flat was not greatly differed seasonally. The two peaks in the primary production observed over season corresponded rather with the photosynthetic activity of benthic microalgae shown in *figure 5* than the amount of sun light arrived onto the tidal flat. The annual production estimated by an integration of daily production was 50 g C m^{-2} yr^{-1}.

5.5 Secondary production of bivalves : *Mactra, Ruditapes* and *Sinonovacula*

Most observations on *Mactra veneriformis* derived from the outer intertidal of Incheon-Songdo tidal flat. Monthly samplings from March 1989 to September 1990 showed a unimodal pattern of the size distribution till August 1989. But newly-emerged juveniles at 10-20 mm shell length (mean of 13 mm) first appeared in September and, therefore, the size frequency curve became a bimodal pattern. The juveniles recruited in September reached the mean length of 30 mm in next September. The growth in shell length and flesh dry weight over season are plotted in *figure 10*. Changes in the flesh dry weight over time showed a peak in the end of June in 1989. The weight increased sharply from April to June and then decreased till July. The weight loss during July was thought to be related with the spawning. Assuming the egg release in July, the shell length of each year class can be defined by reading the length of July : the spat reached the mean length of 25 mm after one year, 33 mm after two years, 38 mm after three years and 42 mm after four years. The mean length of five year old shells was 45 mm in July.

Sinonovacula constricta is a razor clam whose shell length is nearly 10 cm when clams are five years old. The breading cycle of the razor clam *Sinonovacula constricta* was similar to that of *M. veneriformis*. The rapid increase in weight was observed from March to June 1993. The egg release took place till September as supposed by data on the weight. The curves on weight increase and loss indicated a longer spawning season compared to *M. veneriformis*. Spats were found from September in the field, but mass occurrence was recorded in the next spring.

Table 3 summarizes the annual production of clams estimated by Ricker's model based on data collected from the field observations at different localities. The production described in *table 3* is the net production in which the fisheries catches and loss by death are excluded. The highest production was shown by the razor clam *Sinonovacula constricta* and the lowest by surf clam *Mactra veneriformis*, but the latter showed the highest *P/B* ratio. The mean biomass of *M. veneriformis* was 629 g TWW m^{-2} and this estimate comprised to the weight of about 200 individuals. The individual weight of 3 g was then resulted. This size of individuals are less than two years old. The highest biomass of 2,678 g TWW m^{-2} was recorded by the razor clam *S. constricta*. The mean individual weight of 20 g, which weighed seven times of *M. veneriformis*, could also be estimated from the mean density data recorded as 130 g TWW m^{-2} on the Hwaseng tidal flat.

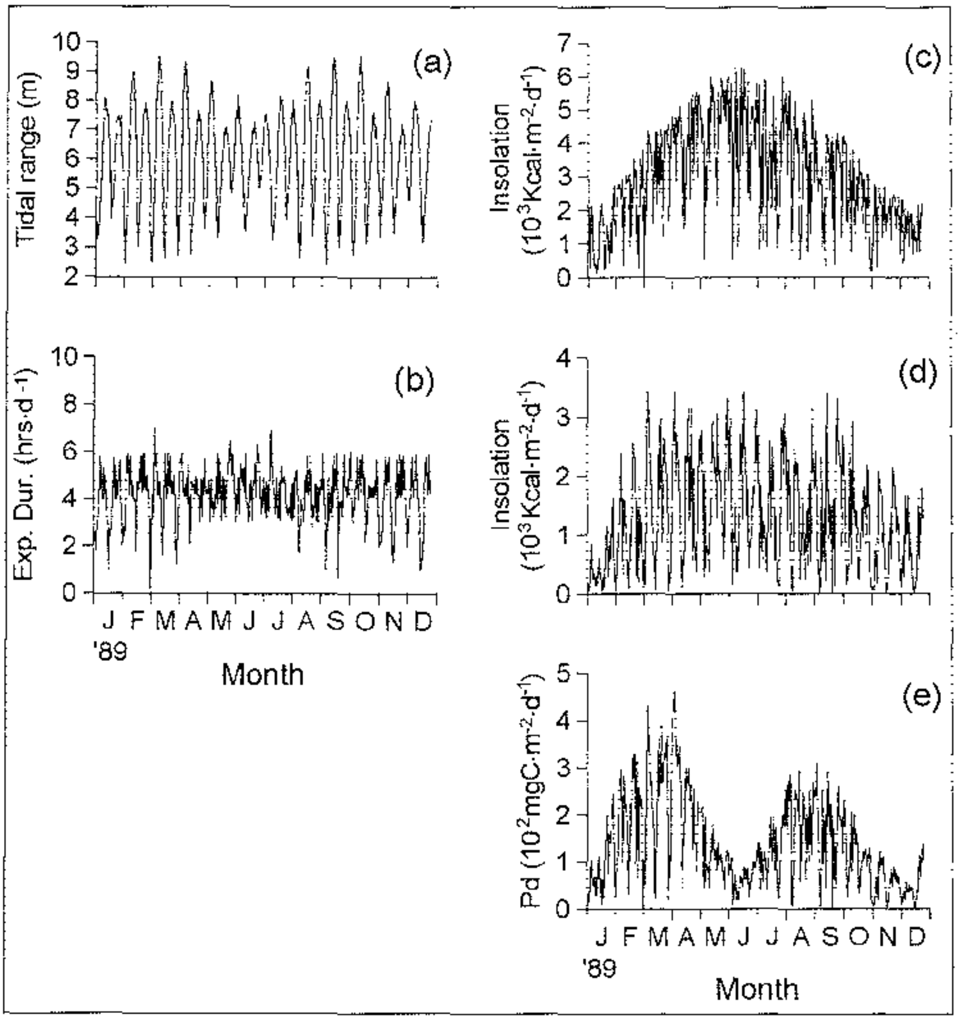
Table 3. – Estimates of the annual production (g DW m^{-2} yr^{-1}), annual mean biomass (g DW m^{-2}), Mean density (indiv. m^{-2}) and P/B ratio of clams on the Korean tidal flat are listed (DW ; flesh dry weight). In the parenthesis are the total wet weight (g TWW m^{-2}) including shells.

Species name	Annual Production	Biomass	Mean density	*P/B* ratio	Locality
Mactra veneriformis	68 (1,358)	31.5 (629)	205	2.15	Incheon-Songdo
Ruditapes philippinarum	83 (1,635)	62.0 (1,221)	292	1.34	Daesan
Sinonovacula constricta	150 (2,998)	134.0 (2,678)	130	1.12	Hwasung
Benthic microalgae	50 g C m^{-2} yr^{-1}				Incheon-Songdo

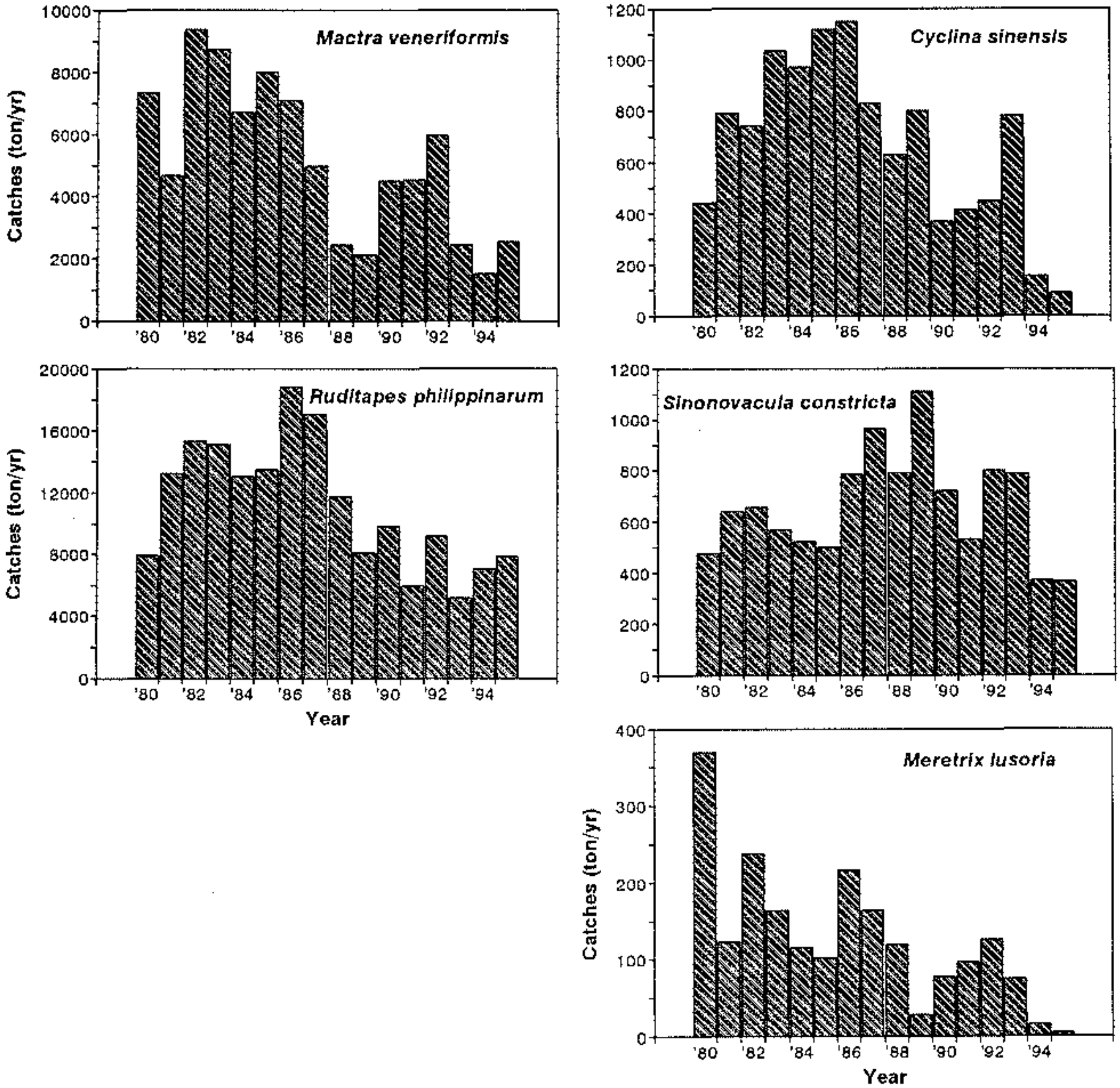
5.6 Commercial Catches of Bivalve

The high productivity of bivalves on the Korean tidal flat can also be demonstrated by examining the statistics on the fisheries catches landed at the collection centers of fisheries ports. The commercially important fisheries catches around the Korean coast are drawn from four groups : shell fishes, crustaceans, echinoderms and macroalgae. Of these groups, the various shell fishes constitute by far the greatest tonnage. The oysters, short necked clams (Manila clam), mussels and cockle shells account for the largest tonnages of catches. Of the mollusks, hen cockles, pen shells, surf clams, razor clams and Venus clams have catched mostly on the west coast. All those are bivalves catched from the tidal flat, beside the pen shell inhabiting the sand bottom of the subtidal area in the west. The second largest group landed on the west coast are macroalgae cultivated in shallow waters near the tidal flat.

In recent years, there have been abundant examples of the decline of fisheries catches of all types around Korean coast. Some of these declines are exemplified by landings of bivalves on the west coast (*fig. 6*). Until 1986, the annual catch of the surf clam *M. veneriformis* was about 70 thousands metric tons, however, it declined to about 30 thousand metric tons after 1986. The yield which we had reached before 10 years has not recovered till today. *Ruditapes philippinarum* was the clam of which the annual catch was two-folds higher than that of *M. veneriformis*, however, the catch at present is only about 60 thousands metric tons per year. The total catch of the Venus clam *Cyclina sinensis* is much lower than the above two bivalves species, but the decline in the catch is clearly shown. The hard clam *Meretrix lusoria* was known to be the best tasted bivalve in Korea and large portion of the landings had been exported to Japan. The annual yield in 1995 is only about 10 metric tons. *Meretrix lusoria* was a typical clam for sand bottom on the Incheon-Songdo and Kimje tidal flat in the west. The only catch which not declined is the razor clam *Sinonovacula constricta*, but the occurrence is restricted rather to the mud flat, and therefore the annual catch is only in small amount.



5. Tidal ranges recorded at Incheon Harbor (a) and the duration of tidal exposure at Incheon-Songdo (b). The insolation at Incheon-Meteor Station (c) is converted to the insolation received during those exposures on the tidal flat (d). Daily primary production (e) are then estimated from the sun light environments and P-I curves obtained from field experiments.



6. Annual changes in fisheries catches of commercial bivalves around the Korean coast.

Although not depicted in a figure, commercial catches in the Kyeonggi Bay which possesses the broadest tidal flat in the west showed a sharp decline in the catch of *M. veneriformis* from 1988. Monthly catch of about 600 metric tons recorded in the Kyeonggi Bay comprised to about 80 % of the total catch from the Korean coast. The tonnage of *R. philippinarum* from the Kyeonggi Bay in 1987 was down from 1988 when landings were about 800 metric tons per month. The decline in the catch of *Cyclina sinensis* is also clear, however, the yield was down from 1990. The recent landings of *M. lusoria* is extremely small compared with those recorded in the beginning of 1980's.

5.7 Reclamations of the Tidal Flat

Korea (south) possesses long stretches of coastal line due to the dented coastal geomorphology. The length of coast line is about ten times longer than the line which connects straightway the cities around the coast *(table 4)*. South coast is a typical rias and a large number of bays are developed. The coast line in the south is longer than that of the west, but the coastal zone in the west has long been exposed to the human alteration, because of the broad tidal flat (2,336 km^2) and the high energy of the tide existed on the coast.

The short historic review of the reclamation on the Korean tidal flat given in *table 4* indicates that a significant portion of the tidal flat is reclaimed since 1960. But human alteration has begun in the 1920's during the period of Japanese occupation. Rice production was the main purpose of the deterioration. The character of the native vegetation near the coast, the salt marshes, had been considerably modified already at the time of the Japanese occupancy. At present typical salt march flora could be found in a stripe just near the bank. Statistics reported the areal extent of the tidal flat as about 2,800 km^2, but it had excluded the area of 405 km^2 tidal flat transformed into agricultural land in 1920's.

The first phase of the intensive alteration by the Korean central government is the years of 1960's. Korean economies began a period of unprecedented growth in that decade. Leaders began to look to the plain land on the coast to feed their citizens by altering the land off the coast to the agricultural. Nearly 400 km^2 of tidal flat in the west was separated from the sea during the period of 1960's

Table 4. – Areal dimenstion of the coastal zone, tidal flats and reclamations carried out in the recent history, Korea (south).

1) Length of the coast line (km)	11,542				
(west coast 3,341, south coast 37,510, east coast 691)					
2) Areal dimension of the coastal zone (km^2)					
Exclusive Economic zone	447, 000				
Within 3 sea-miles	13,000	(less than 20 m depth 12, 000)			
Tidal flats	2,815	(west coast 2,336, south coast 479)			
3) Areal dimension (km^2) of the tidal flat on the coast of provinces of :					
Kyeonggi	810.3 (28.8 %)	Incheon 266.3 (9.5 %)		Chung-Nam 502.9 (17.9 %)	
Jeon-Buk	218.9 (7.8 %)	Jeon-Nam 946.6 (33.0 %)		Kyeong-Nam 47.0 (1.7 %)	
4) Areal dimension (km^2) of the tidal flat reclamation in the recent history					
1917-38	405.4	1946 60	6.3	1961-69	172.2
1970-79	193.7	1980-89	93.1	1990-94	98.5
1995-continuing	764.0	total area including the continuing			1733.2

to 1970's. The recent years of 1990's could be considered as the second period in which the intensive coastal alteration had been taken place. During the first half of 1990's, an area of about 100 km^2 tidal flat was already altered to the land. Severe deteriorations are anticipated because of the on-going projects launched recently. The total area of the reclamation proceeding today covers 764 km^2.

The largest land earning will be taken place from the Kimje tidal flat. The company Nong Jin-Gong, of which the budget is partitioned by the central government, has launched the so called « Sae-Man-Keum » project in 1991 with an expectation of accomplishing the project in 2004. At present the 33 km long dike is in construction. The land earned from this project will be amounted to about 400 km^2. The lake which will be produced after cutting the sea covers an area of 120 km^2. The land which is to be exposed to the human use is then 280 km^2. Two thirds of the land are being used for agriculture and the rest is planned for industrial use and housing to expand the city near around.

The recent alteration of the coastal morphology in the Kyeonggi Bay is also remarkable. An area of 50 km^2 tidal flat developed to the SW direction from the Yeongjongdo is barriered to build an airport. The 17.3 km dike surrounding the area is constructed in 1992. The 10 m high dike was designed to protect the airport land which is in the level below high water or even below mean sea level. The Panweol tidal flat located about 20 km far from the Yeongjongdo tidal flat to SE is also a typical area reclaimed recently. A 12.6 km long barrier was completed in the beginning of 1994 and the land earned from this project was amounted to about 170 km^2. One third of the land is being used for an industrial purpose and the rest is left for agriculture. The pollution problem in the lake Sihwa, which was previously a tidal channel area, was shortly mentioned in the Introduction section. At present the number of reclamation project is amounted to a total of 23 on the Korean west and south coast [26].

VI ■ DISCUSSION

The mass reclamation on the Korean coast in recent years was remarkable compared with those landers on the North Sea coast. However, the values of Korean tidal flats should be assessed by an ecological and environmental view point. Primary and secondary productions recorded in the study areas rival those of Wadden Sea area [16, 17, 18]. The reclamation projects have frequently been supported by the Ministry of Agriculture, Korea, with emphasis on a development of rice field on the tidal flat. The present study indicates, however, that production of bivalves which can be yielded by fishermen comprised to those of rice production. The annual income of fishermen earned by catching the bivalves, *Mactro veneriformis*, amounted to about 0.8 million US$ per km^2. In the case of the razor clam, *Sinonovacula constricta*, the annual income has been reached to about 2 million US$ per km^2 because of the higher market price of the razor clam. Although the economic importance of fisheries has generally been declined on the Korean coast, the tidal flat sustains the capacity of fisheries catches and therefore possibilities in economic uses are still remained.

It is well known that the tidal basins act as traps for pollutants and places for mineralization of those materials [19]. The levels of pollutants in the Korean coastal waters have rapidly been increased in recent years and a reason for that was supposed to be related with those embankments of tidal flat area [20, 21]. A concrete example can be shown from the saline lake Sihwa which was isolated from the sea by a dike construction in 1994. A sharp increase in concentrations of heavy metals and organic materials in lake sediments are reported [22]. The bottom fauna was characterized by a high dominance of the polychaete, *Polydora ligni*, which was known to be tolerant to organic pollution in sediments with high sulfide [23]. Even an azoic zone of several km^2 was found.

We are collecting data describing the actual situation in needs for industrial land uses and the corresponding plans for developments of coastal area around the Korean coast. Actual status of the Korean tidal flat which can be described in terms of ecological values is not well known. It was clear, however, that the Korean tidal flat has been deteriorated through the land reclamation without any assessment of following effects of those deformations on the coastal ecosystem. Comparing the coastal uses in Korea with others of developed countries, e.g. Netherlands and German along the North Sea coast, it can be indicated that the Korean central government policy on the conservation and uses of tidal flat is still in primitive stage.

The coastal lander of Wadden Sea have established the concept of wise use and sustainable development enforcing a better conservation strategy to manage the Wadden Sea ecosystem [24]. Three countries including Denmark have decided to develop a common approach which can be characterized by a complex strategy composed of several steps. A description of the actual situation of the coastal environment and an establishment of the goal by defining a reference situation were elements for accomplishing the purpose agreed between the Wadden Sea countries. Monitoring and research programs were proposed to reach the goal to the conservation and wise use of tidal flats. At the European level, an assessment of the quality of tidal flat ecosystem have already been progressed [2, 3].

The situation in Korea should better be improved as far as it concerns the conservation strategies of tidal flats. Even an assessment of tidal flat ecosystem have little been attempted. Many works are needed to develop a program for conservation and wise use. A more important aspect is, however, that the ecological assessment should be included in planning of land uses and inevitable setting of industrial complexes. Still yet, policy makers tend to establish projects of tidal flat reclamation rather in developmental aspects, not in ecological. A tidal power plant projected to Sihwa area would be an example to compromise the development policy with environment [25]. If the level of pollution in the lake Sihwa could not be lowered without a continuous flushing, then the flushing by an operation of a tidal power plant on the dike would contribute to improve the situation in the lake.

REFERENCES

[1] HUH H.T. (1981). – Feasibility study of Garolim tidal power plant : Hydrographical, meteorological, geophysical, sedimentological, ecological surveys and tidal model studies. Korean Ocean Research and Development Institute (KORDI) report, BSPI 00027-47-2.

[2] Nationalpark Niedersaechsisches Wattenmeer (NNW) (1994). – Oekosystem Forschung, Wattenmeer Niedersachsen. Nationalparkverwaltung Niedersaechsisches Wattenmeer.

[3] Nationalpark Schleswig-Holsteinisches Wattenmeer (NSHW), 1994. Oekosystem Forschung Schleswig-Holsteinisches Wattenmeer, Schriftenreihe Heft 5. Landesamt fuer den Nationalpark Schleswig-Holsteinisches Wattenmeer.

[4] WELLS J.T. and HUH O.K. (1984). – Fall-season patterns of turbidity and sediment transport in the Korea Strait and southeastern Yellow Sea, in Ocean Hydrodynamics of the Japan and East China Seas. Elsevier Sci. Pub., pp. 387-397.

[5] PARK Y.A. (1987). – Coastal sedimentation in estuarine, bays and tidal flats of Korea. *In* : D.-S. Lee (ed.) *Geology of Korea*. Geology Society of Korea. Kyohaksa, Seoul, pp. 389-405.

[6] YI S.U. (1972). – On the tides, tidal currents and tidal prisms at Incheon Harbor. J. Oceenol. Soc. Korea, 7 : 86-97.

[7] LEE C.B., PARK Y.Y. and KOH C.H. (1985). – Sedimentology and geochemical properties of intertidal surface sediments of the Banweol area in the southern part of Kyeonggi Bay, Korea. J. Ocenol. Soc. Korea 20 : 20-29.

[8] WELLS J.T. and PARK Y.A. (1992). – Observations on shelf and subtidal channel flow : implications of sediment dispersal seaward of the Keum River esteary, Korea. Est. Coastal Shelf Sci., 34 : 365 – 379.

[9] WELLS J.T. (1995). – Tide-dominated estuaries and tidal rivers. In : G.M.E. Perillo (ed) Geomorphology and Sedimentology of Estuaries. Developments in Sedimentology 53. Elsevier Sci. Pub., pp. 179-205.

[10] Office of Hydrographic Affairs, Republic of Korea (OHAROK) (1987). – Technical reports of hydrography, 1987. Office of Hydrographic Affairs, Korea. 199 p.

[11] LOHMAN K.E. (1972). – A procedure for the microscopical study of diatomaceous sediments. Nova Hedwigia Beih., 39 : 267-283.

[12] JOH S.O. and KOH C.-H. (1991). – A computer program, MAPP, for the estimation of the macroalgal annual production from photosynthetic rates and biomass changes. J. Oceonol. Soc. Korea, 26 : 291-294.

[13] RICKER W.E. (1946). – Production and utilization of fish population. Ecol. Monogr., 16 : 373-391.

[14] SHEPARD F.P. (1954). – Nomenclature based on sand-silt-clay ratios. J. Sed. Pet., 24 : 151-158.

[15] PAIK E.I. (1977). – Studies of polychaetes annelid worms of the family Nereidae in Korea. Res. Bull. Hyosung Women's Coll., 19 : 131-227.

[16] BEUKEMA J.J. (1980). – Calcimass and carbonate production by molluscs on the tidal flats in the Dutch Wadden Sea. I. The tellinid bivalve *Macoma balthica*. Neth. J. Sea Res., 14 : 323-338.

[17] BEUKEMA J.J. (1983). – Calcimass and carbonate production by molluscs on the tidal flats in the Dutch Wadden Sea. II. The edible cockle, *Cerastoderma edule*. Neth. J. Sea Res., 17 : 301-305.

[18] WARICK R.M. and PRICE R. (1975). – Macrofauna production in an estuarine mud-flat. J. Mar. Biol. Ass. U.K., 55 : 1-18.

[19] HENRIKSEN K., JENSON A. and RASMUSSEN M.B. (1984). – Aspects of nitrogen and phosphorus mineralization and recycling in the northern part of the Danish Wadden Sea. Netherlands Institute of Sea Research. Publication Series 10 : 51-69.

[20] Ministry of Environment, Korea (MEK), 1996. Environmental status, Korea. 597 p. (in Korean).

[21] KOH C. H. (1996). – Coastal pollution in relation to coastal development. In : Symposium on the problem of marine pollution, Korea. Association for Marine and Fisheries Research of the Tokdo Area, 53-80.

[22] LEE J. H. and KOH C.H. (1997). – Soft bottom fauna in and off a heavily polluted saline lake after embankment on the west coast of Korea (in preparation).

[23] PEARSON T. H. and ROSENBERG R. (1978). – Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev., 16 : 229-311.

[24] Common Wadden Sea Secretariat (CWSS) (1992). – Wise use and conservation of the wadden sea. The Common Wadden Sea Secretariat.

[25] SONG W.O. and YUM K.D. (1996). – Korean tidal power projects. Present status. The proceedings of the The 30th aniversary of La Rance tidal power station.

[26] Rural Development Corporation, 1996. Tideland Reclamation in Korea.