Bull. Mar. Res. Inst.
Cheju Nat. Univ., 17 : 69~83, 1993

濟州大 海洋硏報, 17 : 69~83, 1993

Changes in Fisheries Resources and Future Research Need for the Yellow Sea Ecosystem

Chang-Ik Zhang* · Sin-Jae Yoo · Myoung-Ho Sohn

**Department of Marine Development Kunsan National University, Kunsan, 573-360, Korea*
Korea Ocean Research and Development Institute Ansan P. O. Box 29, Seoul, 425-600, Korea

황해생태계에 있어서 수산자원의 변동과 연구과제

장창익* · 유신재 · 손명호

*군산대학교 해양학과, 한국해양연구소

Korean annual catches from the Yellow Sea have been gradually increased until the mid 1980s, showing about 130,000 metric tons (mt) in the 1960s, 300,000 mt in the 1970s, and 450,000 mt in the 1980s. Three major fisheries, that is, the two-boat large bottom trawl fishery, the large staw net fishery and the medium-sized bottom trawl fishery, accounted for about 70% of the total catch from the sea. During the three decades the catch per unit of effort (CPUE) declined substantially, indicating that the relative abundance of the 1960s was reduced by about one tenth of that of the 1980s for all of the three fisheries, due possibly to overexploitations of the fish stocks. In addition species compositions in the catch revealed a remarkable change in species dominance for the same period. Nine species, which are anchovy, hairtail, small yellow croaker, filefish, mackerel, Jack mackerel, Spanish mackerel, skaterays and pomfret, were consistently dominant in the catches as well as commercially important. There was a general trend of species shifts in species compositions from large, high-valued fishes to small, low-valued fishes.

Key words : fisheries, resources, abundance, dominance, ecosystem

INTRODUCTION

During the last three decades the fishing areas of Korean coastal and offshore fisheries have been extended continuously (Fig. 1). In the 1960s the major fishing ground in the west and south of Korea was confined within the Yellow Sea. The Korean fisheries have extended their fishing ground a little toward the northern part of the East China Sea in the 1970s. In the 1980s, however, the fisheries have greatly extended their fishing area almost twice larger than that of the 1970s, covering the entire East China Sea. This phenomenon might attribute to the decline in the major fisheries resources in Korean waters of the Yellow Sea as well as the motorization of

제주대학교 해양연구소에서 개최한 제6회 해양과학심포지움(1993. 12. 10.)에 발표된 내용임.

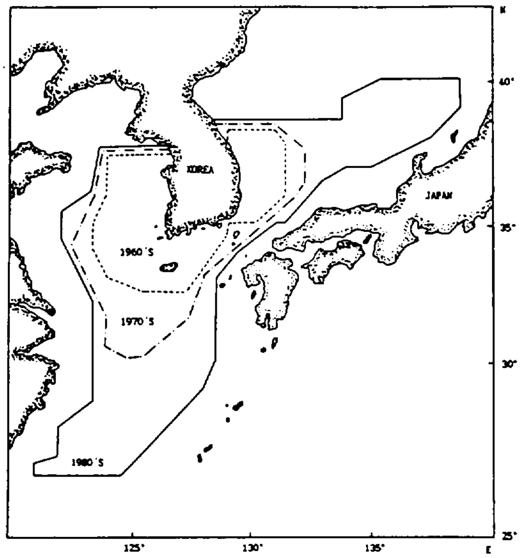

Fig. 1. Changes in fishing areas of Korean coastal and offshore fishieries, 1960s~1980s.

their fishing vessels (Zhang *et al*, 1988).

Korean fishermen have traditionally utilized the Yellow Sea as one of the major fishing areas. The annual Korean catch from this water ranged from 70,000 to 500,000 metric tons (mean : 290,000 mt, CV : 45 %) during the last thirty-year period, accounting for about one third of the annual catch from the overall Korean coastal and offshore fisheries (Fig. 2).

In the Yellow Sea, among three major fisheries, that is, the two-boat large-sized bottom trawl fishery, the large staw net fishery and the medium-sized bottom trawl fishery, the large staw net fishery showed the largest catch and followed by the two-boat large bottom trawl and the medium-sized bottom trawl fishery.

The objective of this paper is to examine historical changes in the abundance of major fisheries resources and their species compositions in the Yellow Sea, based on available data and fisheries literature, and also to discuss needs for cooperative scientific research, for establishing effective monitoring system and for developing cooperative fisheries management system in the Yellow Sea ecosystem.

MATERIALS AND METHOD

We used annual total catches and fishing efforts in terms of the number of the vessel and horse power by fishery type in 1984~1990 from Statistical Yearbook of Agriculture, Forestry and Fisheries to estimate annual catch per unit of effort (CPUE) of the fisheries.

Catch and effort statistics for each resource species were also used to estimate CPUE by species group or by single species as well as species compositions in 1984~1990 from Statistical Yearbook of Agriculture, Forestry and Fisheries.

Data on oil spills were derived from KORDI (1990a), and data on heavy metals were derived from KORDI (1990b).

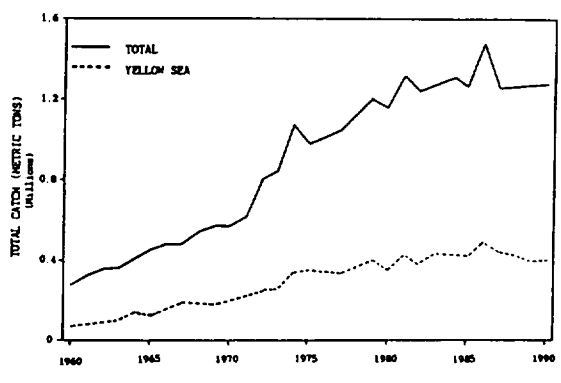

Fig. 2. Catches by Korean coastal and offshore fisheries and catches from the Yellow Sea, 1960~1990.

RESULTS

Changes in Fisheries Yield and CPUE

Yields by the Korean coastal and offshore fisheries gradually increased year after year until early 1980s. Annual yields from the Yellow Sea have also increased during the same period. However, they remained at a 400,000 mt level since 1981, in spite of the continuous increase in their fishing efforts (Fig. 3), as well as the extension of their fishing grounds as shown in Figure 1. Both the number of fishing vessels and their horse powers (HPs) have increased continuously during the last three decades (Fig. 3). Even though the number of vessels remained the same since early 1980s, their HPs kept increasing.

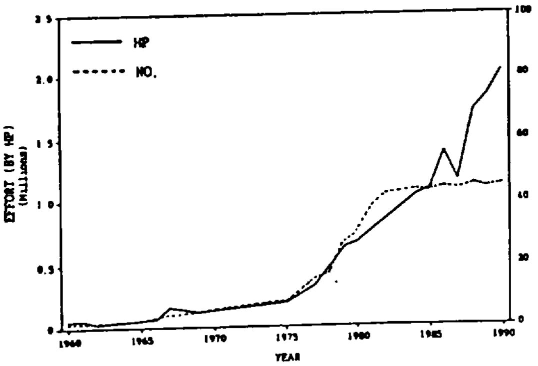

Fig. 3. Fishing efforts in terms of the number of vessels and the horse powers (HPs) of Korean Yellow Sea fisheries, 1960~1990.

The number of species commercially harvested in the Yellow Sea was more than 30 including shellfishes as shown in Table 1. Demersal species were the major component of the fisheries resoures in this area, comprising 50 to 70% of annual total catch from Korean fisheries in the Yellow Sea (Fig. 4). The others were pelagic and shellfish species, which were almost equivalent in the amount of their catches.

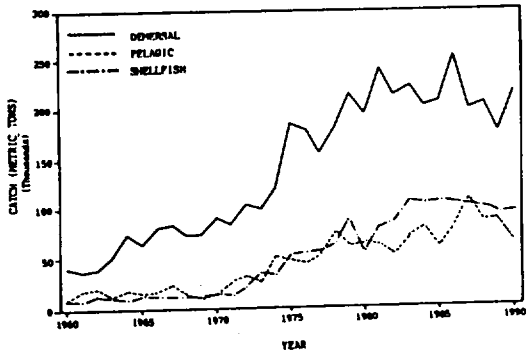

Fig. 4. Catches by three groups of animals, in the Yellow Sea, 1960~1990.

Figure 5 shows changes in annual catch per unit of effort (CPUE) by Korean Yellow Sea fisheries. The CPUE in terms of both the number of fishing vessels and the horse powers declined gradually until mid-1970s, and since 1976 the CPUE declined substantially until 1980. Then the CPUE in the number of fishing vessels remained at the low level in 1980s, while the CPUE in the horse power continuously declined until 1990.

The three major fisheries in the Yellow Sea showed a similar trend in their annual catches, once increasing for a period and

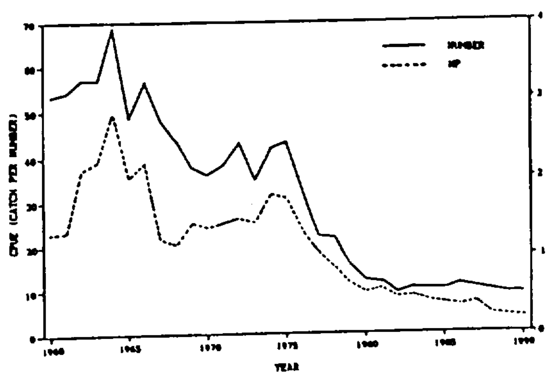

Fig. 5. CPUE by Korean Yellow Sea fisheries, 1968~1990.

declining afterward (Fig. 6). Annual catches of the large staw net fishery increased until 1979, and declined thereafter. Annual catches of the large bottom trawl fishery, however, started declining from 1975, while those of the medium-sized bottom trawl fishery fluctuated until 1982 and then continuously declined.

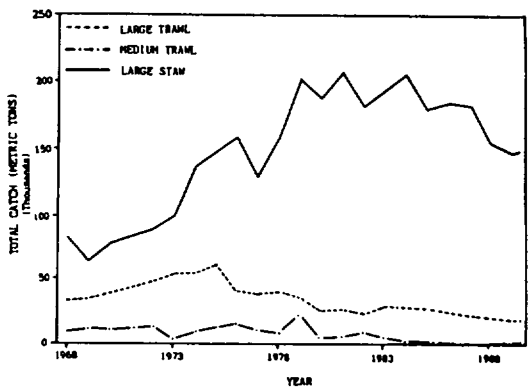

Fig. 6. Catches by three fisheries, large staw net, two-boat large-sized and medium-sized trawls in the Yellow Sea, 1968~1990.

The CPUEs for the three fisheries, i. e., large bottom trawl (Fig. 7a), staw net (Fig. 7b), and medium bottom trawl (Fig. 7c), showed a declining trend in the Yellow Sea. They declined dramatically since 1975 for all the three cases until early 1980s and then moderately declined, indicating that the relative abundance of 1960s was about one tenth of that of the 1980s.

Changes in Species Dominance

Species composition in the catch revealed remarkable changes in the dominant species during the last three decades in the Yellow Sea. Figure 8a shows five major species in the commercial catch by Korean fisheries in the Yellow Sea. Four of them were demersal and semi-demersal species, i. e., small yellow croaker, hairtail, filefish

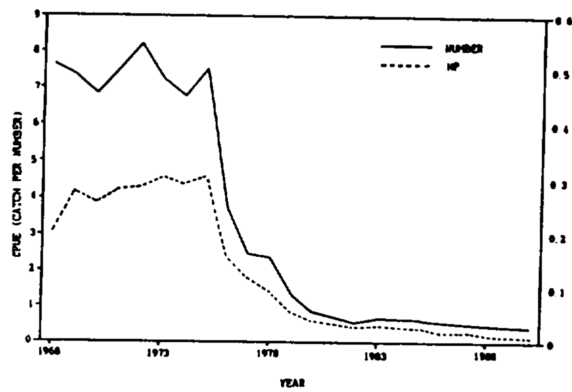

Fig. 7a. CPUE by the large bottom trawl fishery in the Yellow Sea, 1968~1990.

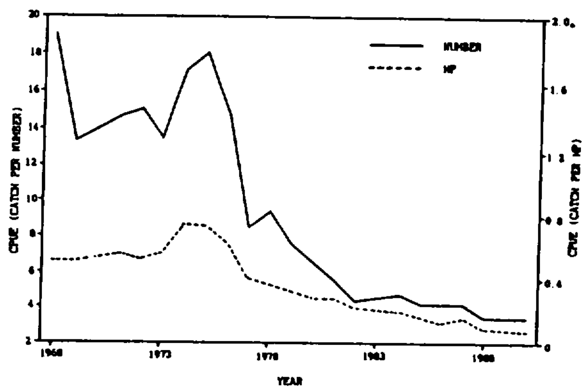

Fig. 7b. CPUE by the staw net fishery in the Yellow Sea, 1968~1990.

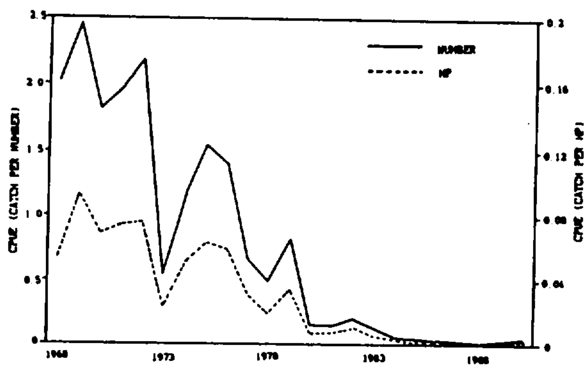

Fig. 7c. CPUE by the medium trawl fishery in the Yellow Sea, 1968~1990.

and corvenias, while anchovy was the only pelagic species. Among the demersal and semi-demersal resource species small yellow croaker was the most dominant species in the 1960s, followed by hairtail, skaterays, pomfret, and so on (Fig. 8b).

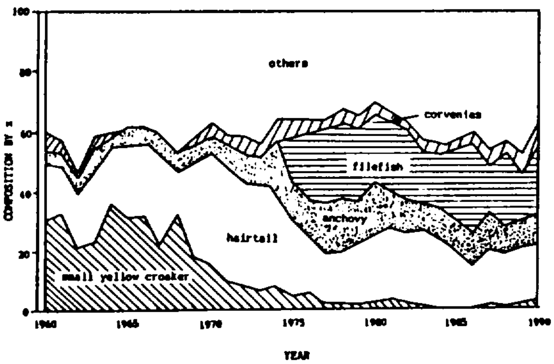

Fig. 8a. Species compositions of catches by Korean coastal and offshore fisheries in the Yellow Sea, 1969~1990.

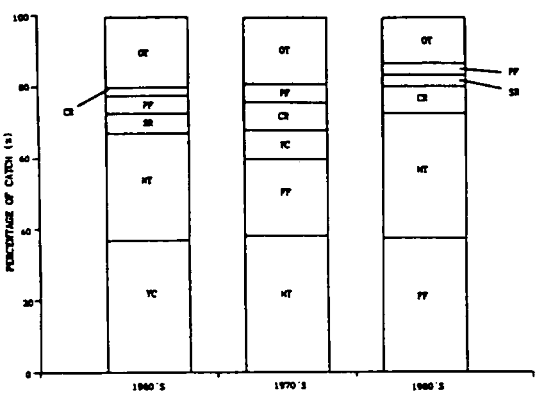

Fig. 8b. Species compositions of demersal fishery by Korean coastal and offshore fisheries in the Yellow Sea by decade.

YC : small yellow croaker
HT : hairtail **FF : filefish**
PF : pomfret **SR : skateray**
CR : corvenias **OT : Others**

In the 1970s, however, hairtail occupied the position of the most dominant species, and filefish suddenly appeared as a major species, followed by small yellow croaker, corvenias, and pomfret. Filefish and hairtail were almost equally dominant in the 1980s, followed by corvenias, skaterays, and pomfret, and small yellow croaker was no longer a major species.

Compared to the demersal and semi-demersal species, the pelagic species had more or less stable species compositions. Among the pelagic resource species anchovy was the most single dominant species during the thirty-year period. Jack mackerel, Spanish mackerel and sardine occupied the second rank in the catches, varying by decade (Fig. 8c).

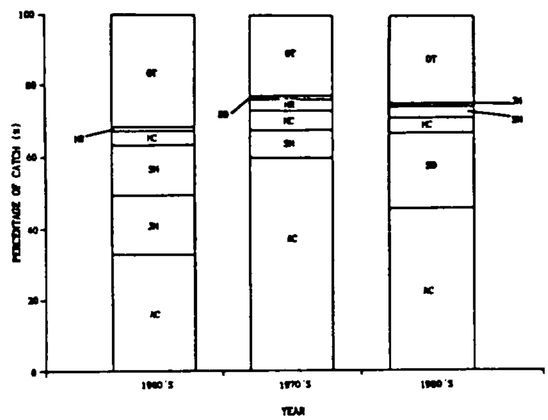

Fig. 8c. Species composition of pelagic fishes by Korean coastal and offshore fisheries in the Yellow Sea by decade.

Stock Abundances

Considering the stock condition of fisheries resource populations, we simply speculate from the declining trend in fisheries yields that most major populations were overfished. Figure 9a shows the CPUEs by Korean fisheries for the major demersal fish species for 1960～1990 in the Yellow Sea. The CPUEs of major species such as, small yellow croaker, hairtail, filefish, pomfret, skaterays, white croaker, flounder and sharptoothed eel, have continuously declined, while those of some minor species such as, see eels and corvenias, have remained at the medium level (Fig. 9a). The CPUEs for the pelagic species have also declined, except for sardine (Fig. 9a). Most of the recent CPUEs were at the extremely low level, compared to 1960s and early 1970s.

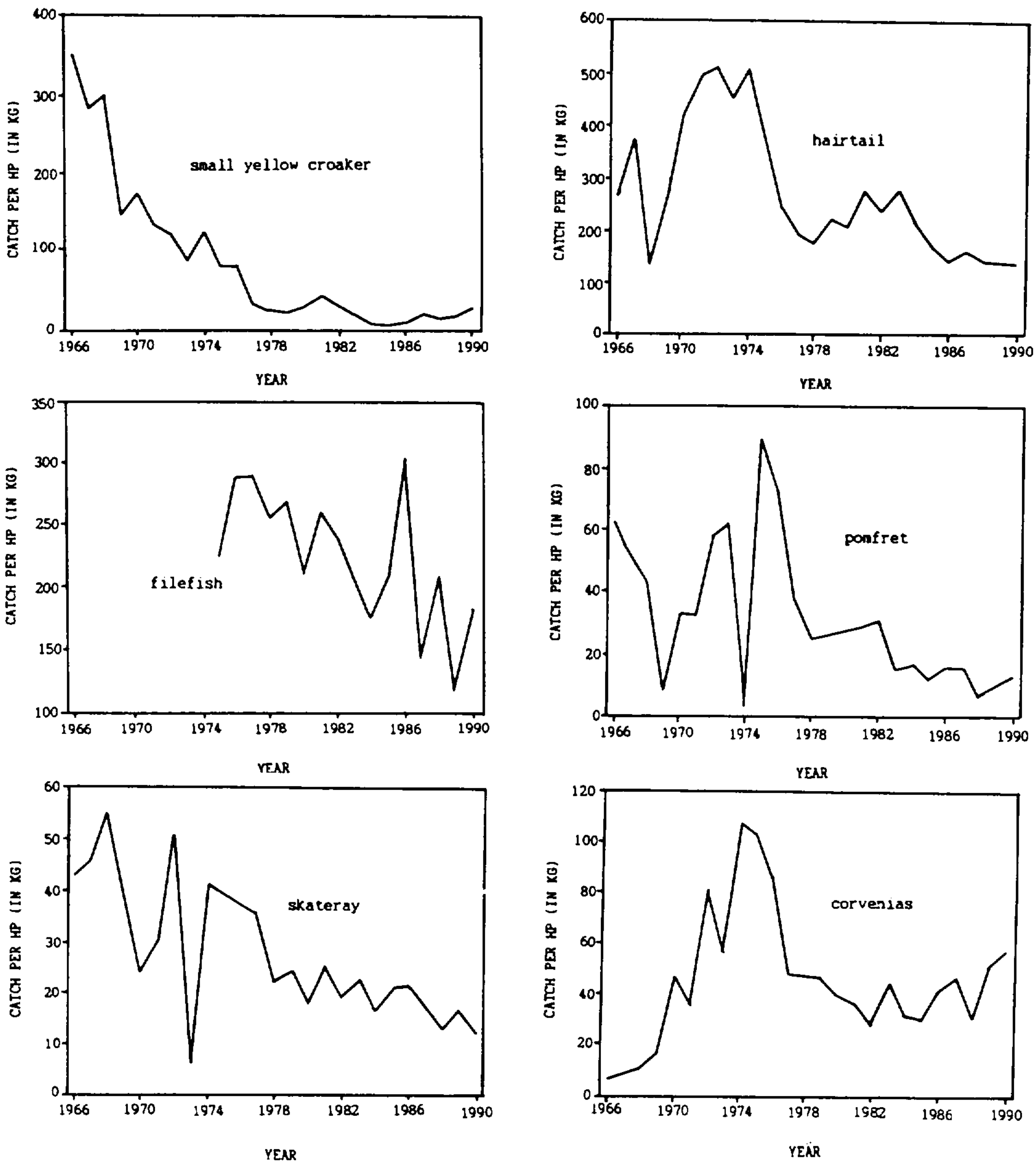

Fig. 9a. CPUE of major demersal species by Korean coastal and offshore fisheries in the Yellow Sea, 1966～1990.

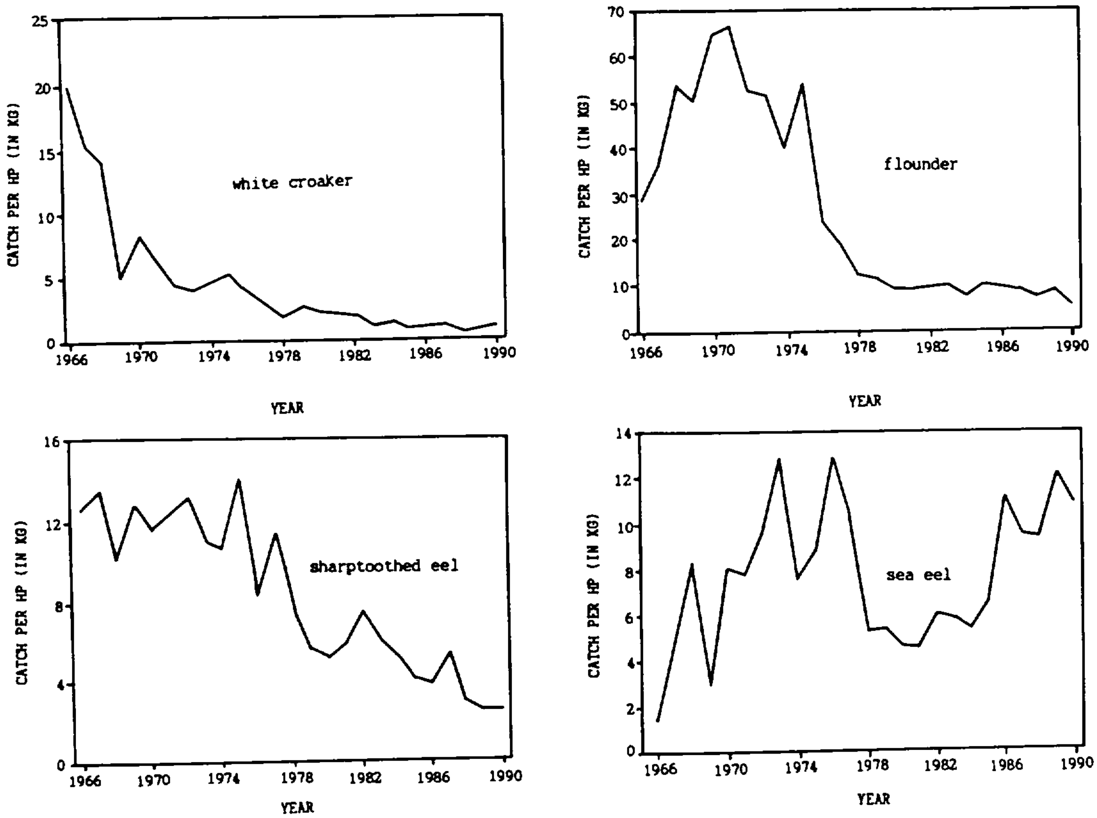

Fig. 9a. - continued.

For assessing the condition of major fish stocks, we demonstrate the stock condition of small yellow croaker, *Pseudosciaena polyactis* as an example, which is a typical demersal species and has been the most important species in Korean waters. All evidence indicates a decline in stock abundance of this species in Korean waters since 1960s (Zhang *et al*, 1992a). Results from cohort analysis suggest a severe decline in the stock even from 1970s to 1980s. The estimated total and adult biomass of the stock declined more than 5-fold within the above 10 years. The decline in the stock was caused mainly by the high fishing intensity in the 1980s which was twice as high as that in 1970s (Zhang *et al*, 1992b), which in turn exceeded the F_{msy} level based on a surplus production analysis. This was also true in the Chinese side of the Yellow Sea, according to Tang (1989) and Yu (1991). Figure 10 shows the production curve of three major offshore species such as, the large yellow croaker, the small yellow croaker and hairtail in China from 1957 to 1983. The catch of the small yellow croaker was drastically reduced from 163, 000 mt in 1957 to 29, 000 mt in 1983. This trend was similar to that of Korean small yellow croaker fisheries in the Yellow Sea. Yu (1991) stated that in the Chinese water the sharp reduction in yellow croakers' production was attributed to depleted stocks caused by persistent large-scale overfishing, to such an extent that even the overwinter parent fish could hardly escape landing. According to the yield per recruit analysis and a simulation study,

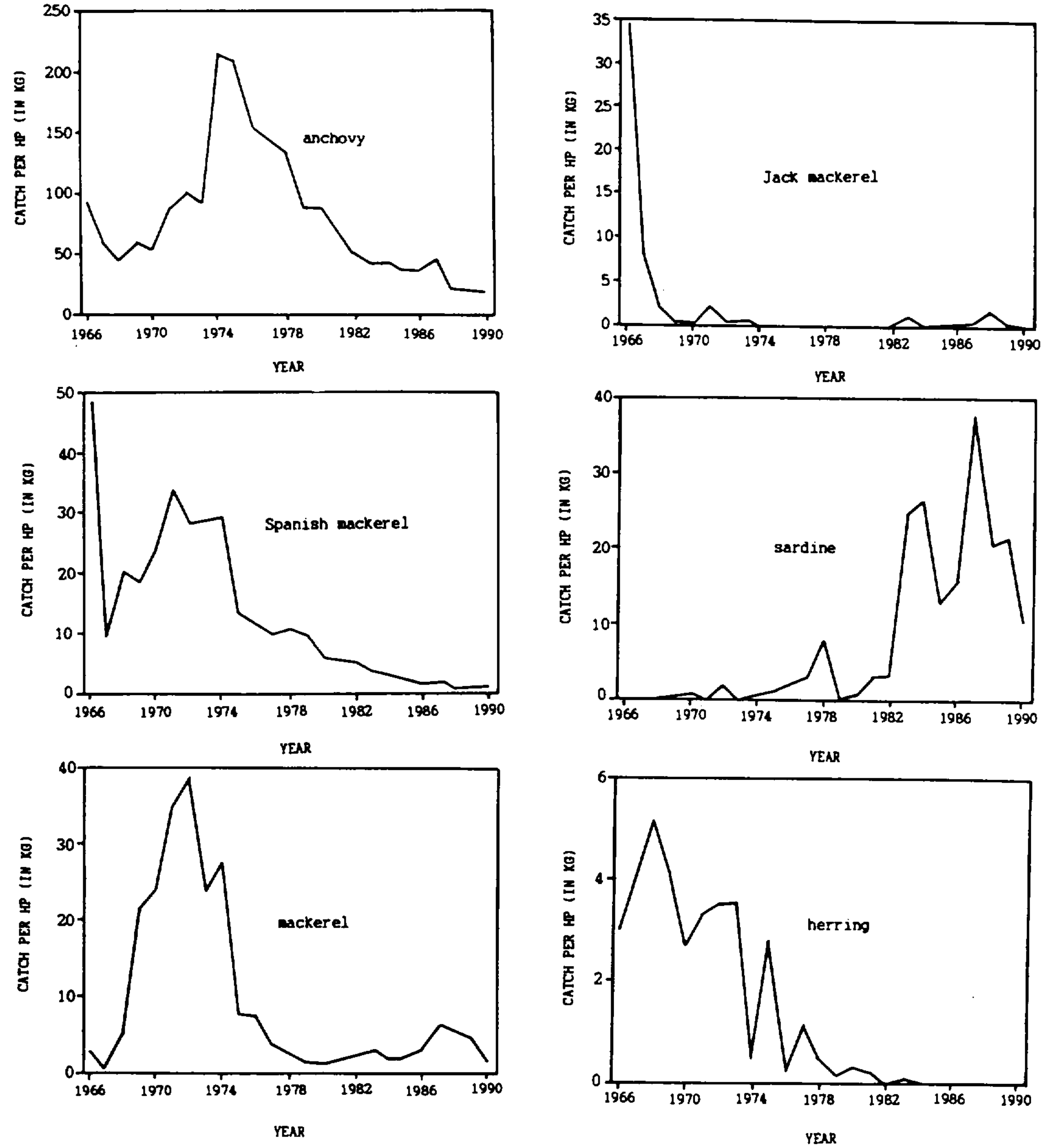

Fig. 9b. CPUE of major pelagic species by Korean coastal and offshore fisheries in the Yellow Sea, 1966~1990.

both a reduction of fishing intensity and an increase in age at first capture should be considered for rebuilding the croaker stock and maintaining it at a maximum sustainable level (Zhang and Yoo, 1992)

Other Potential Factors Affecting Fisheries Resources

Since the commencement of the Economy Development Plan of Korea in the early 1960's, land reclamation has been done

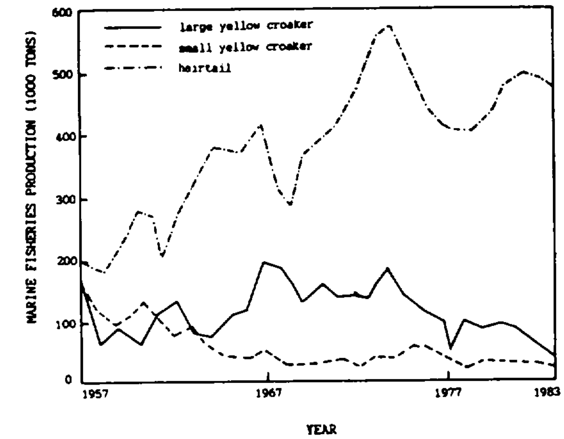

Fig. 10. Production curves of yellow croakers and hairtails (from Yu, 1991).

extensively along the west coast of southern half of the Korean peninsula, and the trend is ever increasing. Ongoing activities since 1989 almost reach the same level as of 1962~1988. The reclaimed area per year increased more than ten times (Fig. 11).

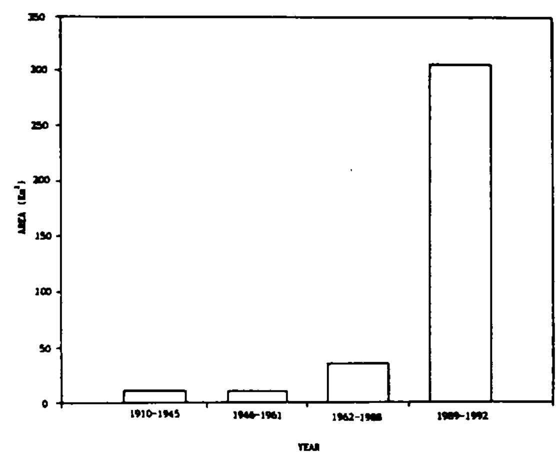

Fig. 11. Areas of land reclamations by year in Korea, 1910~1992.

Of these current activities, Yellow Sea shore comprises 95.9% of the total area (914㎢) because of its well-developed tidal flats (Fig. 12). The available area for land

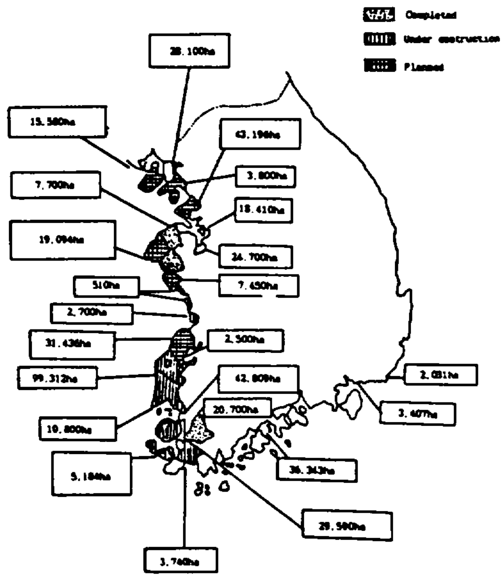

Fig. 12. Location and areas of land reclamation in Korea.

reclamation in the west coast of Korea was estimated to be 4, 075㎢. In North Korea, about 600~ 700㎢ has been reclaimed and 33, 000㎢ is planned. It is obvious that land reclamation would be continued in the future.

The adversary effects of land reclamation on fisheries can be of many aspects; destruction of spawning and nursery grounds, contamination related to construc-tion, reduced primary production, changes in circulation pattern, to name a few. Yet few studies has been made to assesss the impacts of land reclamation on fish populations. Considering that many fish species (e.g., small yellow croaker) use the tidal flats of the Yellow Sea as the spawning and nursery ground, the impacts of land reclamation should be closely monitored and studied.

Another factor of environmental deterioration related with the industrial development is oil spills. Oil spills in the Yellow

Sea have been steadily increasing. Figure 13 shows the recent trend of oil spills in Korean waters of the Yellow Sea. Although the quantities in 1990~1992 appeared to decrease, this is due to the decrease of a few huge spill accidents. The frequency, which includes incidental oil spills as well as accidents, is actually increasing. Damage assessments have been made only for the aquacultures not for natural resources. But it is beyond doubt that some damage must be done to natural living resources. With a computer model incorporating lower trophic biota and energy transfer, as well as higher trophic biota and biomass data base for the Yellow Sea, it was estimated that about 32 metric tons of organic production was lost in the long run, if 100 mt of crude oil was spilt in the central part of the Yellow Sea (KORDI, 1990a).

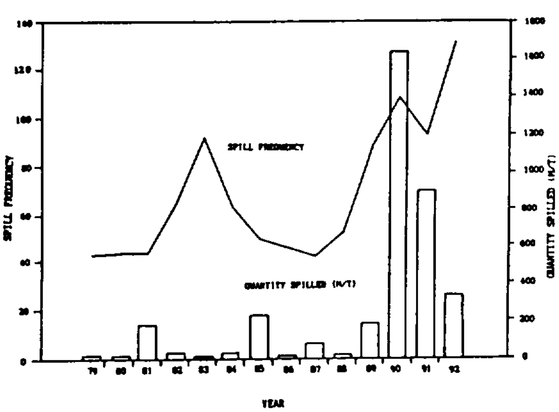

Fig. 13. Oil spill frequencies and quantities in Korean waters of the Yellow Sea, 1979~1992.

To monitor the state of the heavy metal pollution in the coastal waters of Korea, mussel samples were collected from 17 locations along the coast of Korea during 1987~1990 and analyzed for seven environmentally important heavy metals, i.e., copper, cadmium, lead, zinc, mercury, iron, and manganese (KORDI, 1990b). It was found that in general mussels from the west coast (facing Yellow Sea) contained more heavy metals than those from the south of east coast, although slight differences existed from metal to metal. The conclusion was that compared with similar data from the United States and other industrialized countries the heavy metal levels in Korean waters were close to natural background level. During the three years' survey period, there was no indication of increasing level of metal contamination. It was not clear whether the higher level of the west coast was real or due to the higher longevity of specimens.

Few studies have been made to measure pesticides and PCBs level in the sea water, sediment or animal tissue in the Yellow Sea. Chlorinated hydrocarbons are known to be toxic at low level of concentration to various kinds of marine organisms such as, phytoplankton, fish and invertebrates. These compounds are also known to be subject to bioaccumulation and biomagnification. Active agriculture and continuous industrialization on both sides of the Yellow Sea require a serious concern, since these compounds still could reduce the fecundity and survivorship of many marine organisms at sublethal level of concentrations.

DISCUSSION AND CONCLUSION

Need for Cooperative Scientific Research

Understanding a marine ecosystem requires basic knowledge of the hydrography, productivity, and fisheries ecology of the ecosystem. To get the knowledge an adequate data collection and analysis system is essential to provide with a comprehensive database. However, for the Yellow Sea, efforts to study the important features of the marine ecosystem have been less than appropriate. No nation has access to all the relevant information and data that exist. Cooperative studies have not taken place before. A recent report by the FAO called for studies of the hydrography of the Yellow Sea, primary productivity, overall assessment of the demersal fish stocks with emphasis on coastal catches, further research on the biology of pelagic stocks, assessment of the cephalopod resources, assessment of the fleshy prawn stock, and identification and research on coastal pelagic shrimps (Chikuni, 1985).

For conducting this research, international arrangements on data collection, standardization, exchange, analysis, and interpretation should be established to provide a comparable statistical basis for management decisions.

Traditionally, for geographical reasons in the Yellow Sea, Chinese researches were concentrated on the area to the west of 124°E, while Korean researches to the east of 124°E. Thus, there has been a division of labor but without any cooperation. It goes without saying that for a successful monitoring of the whole Yellow Sea ecosystem, a cooperative division of labor is desirable.

To this end, sampling design and methodology of surveys should be carefully arranged. For example, the size of sampling nets for zooplankton study were different between Chinese and Korean surveys, thereby making any comparison difficult. The procedure of the primary productivity measurement should be compared and cross-checked to minimize the experimental differences. Sampling apparatus and methods for the collection of benthic organisms should also be standardized.

Table 1. Major resident species targeted by fisheries in the Yellow Sea

Common name	Species name
Demersal and semi-demersal fishes	
Small yellow croaker	*Pseudoscianena polyactis*
Hairtail	*Trichiurus lepturus*
Filefish	*Navodon modestus*
Pomfret	*Pampus argenteus*
Corvenias	*Collichthys niveatus*
Large yellow croaker	*Pseudosciaena crocea*
White croaker	*Argyrosomus agentatus*
Brown croaker	*Nibea imbricatus*
Roundnose flounder	*Eopsetta grigorjewi*
Bastard halibut	*Paralichthys olivaceus*
Common sea bass	*Epinephelus septemfasciatus*
Pacific cod	*Gadus macrocephalus*
Puffers	Tetraodontidae
Sharptoothed eel	*Muraenesox cinereus*
Red sea bream	*Pagrus major*
Sea-devil	*Lophiomus setigerus*
Bigeyed herring	*Harengula zunasi*
Rockfish	*Sebastes inermis*
Flathead	*Platycephalus indicus*
Skateray	Rajidae
Pelagic fishes	
Anchovy	*Engraulis japonica*
Sardine	*Sardinops melanosticta*
Pacific herring	*Clupea harengus pallasii*
Mackerel	*Scomber japonicus*
Jack (Horse) mačkerel	*Tranchurus japonicus*
Spanish mackerel	*Scomberomorus niphonius*
Shellfishes	
Cuttlefish	*Sepia esculenta*
Blue crab	*Portunus trituberculatus*
Large shrimp	*Penaeus orientalis*
Common squid	*Todarodes pacificus*

More important, sampling stations and time should be arranged so that the results be compared with in appropriate space and time scale. For example, it could be less clear to compare the phytoplankton collected in two regions, one collected in April, the other in May.

Establishing Effective Monitoring System

Recently, both Korean and Chinese scientists are developing so called 'YSLME (Yellow Sea Large Marine Ecosystem) project' with the assistance of NOAA scientists. Table 2 shows the Korean YSLME structure, covering the two core modules, which are productivity and fish community modules. In Korea about 30 specialists in various fields from more than 6 institutions will participate in the YSLME project.

Table 2. Korean Yellow Sea Large Marine Ecosystem Project

Productivity Module
CPR/UOR
- biotic and abiotic variables

Remote Sensing
- SeawiFs, AVHRR

Data Management

Fish Community Module
Distribution & Abundance
- Plankton (nets)
- plagic species (acoustics)
- demersal species (bottom trawls)
- benthos (grab samplers)

Fish Biology
- age and growth
- maturation and spawning
- early life history
- feeding and ecological interactions

Population Dynamics
- stock assessment
- management parameters

Population
- contaminants (water, sediment, organism)
- pathology

In the productivity module various oceanographic parameters will be continuously observed by CPR/UOR and satellite remote sensing. In this module, the plankton productivity and biodiversity are major concern. As we pointed out earlier, there are potential factors diminishing living reasources other than overfishing. In addition, local change in hydrography due to global change is another possibility. These environmental impacts might be indirect and subtle, and perhaps plankton are most vulnerable.

The plankton are important in terms of the health of marine ecosystems in two respects; they might reflect environmental changes such as, circulation and pollution. Also, they compose the basis of marine food webs.

As mentioned earlier, the estimates of yearly primary production were not in consensus. This raises two basic problems in estimating yearly primary production. The first problem is related with the measurement methodology. Using radiocarbon as tracer of the photosynthetic process is most widely used due to its high sensitivity and convenience. This method, however, has so many sources of error (Peterson, 1980) that data from different authors cannot always be compared reliably. The second problem is how the extrapolation of point measurements to yearly production rate should be done given the spatial and temporal variability of marine photosynthetic processes.

Use of CPR/UOR and pump and probe fluorometer (Falkowski *et al*, 1992) can reduce these problems to a certain degree. CPR/UOR surveys can be greately enhanced by synoptic views provided by satellite remote sensing. Sea surface temperature (AVHRR) and primary productivity (SeaWiFS) are such variables measurable by remote sensing.

SeaWiFS would be particularly useful for monitoring coastal waters, since the sensor has more channels as well as better sensitivity (Aiken *et al*. 1992). The channel 1 was added for correction of the contribution from dissolved organic matter. It would be very interesting to compare the images derived from CZCS (1978~1986) with images from SeaWiFS.

Being located at the marginal area of a continent, the optical properties of the Yellow Sea are complicated in terms of both atmospheric correction and in-water algorithm making the interpretation of ocean color images difficult. Yellow dusts make a serious problem of atmospheric noise. As the name implies the Yellow Sea is case Ⅱ water, which means that constituents other than chlorophylls or chlorophyll-derived matters also affect the optical properties of water.

Given sufficient amount of data of primary and secondary productivity together with detailed information of food webs we would be able to address a very important question for management: how much we can exploit from the ecosystem, i.e., potential yield.

In the fish community module four areas will be covered. The research areas are distribution and abundance of major resource organisms, fish biology, population dynamics and pollution. For the area of the distribution and abundance various devices and samplers will be employed to sample the resource organisms, that is, plankton nets for plankton, hydroacoustics for pelagic species, bottom trawls for demersal species, and grab samplers for benthic animals. For fish biology area age and growth, maturation and spawning, early life history, and feeding and species interactions will be studied for major fishes and shellfishes. Based on the above information on the abundance and biological characteristics population dynamics of the major resource organisms will be studied for providing the basis of management decisions, together with the information on the potential yield of the ecosystem derived from the productivity module. Finally, the monitoring of pollution will be conducted by examining contaminants from samples of sea water, sediments and tissues of selected organisms including microorganisms. Also, the pathology of fish and shellfish will be studied to monitor the level of biological influence from pollution.

Developing Cooperative Fisheries Management System

The Yellow Sea is known as one of the most heavily exploited seas in the world, having multigear fisheries targeting on multispecies by Korean (south and north), Chinese and Japanese fishermen (Zhang *et al*, 1988).

A number of fish stocks have begun to be heavily exploited by fishermen of three countries especially with the introduction of bottom trawl vessels in the early twentieth century, and some commercially important species such as red seabream, declined in abundance already in the 1920s and 1930s (Xio, 1960). The stocks remained fairly stable during world war Ⅱ. However, due to a great increase in fishing effort and its expansion to the entire Yellow Sea nearly all the major stocks have been heavily exploited by the mid-1960s (Liu, 1979).

In conclusion most major fisheries resources of the Yellow Sea are fully exploited with the possible exception of a few species. Also, there is no hope that new fisheries resources will be discovered in commercial quantities. Therefore, it is important to conserve the existing stock to ensure that fishing does not deplete them. In Korea some attempts have been made to restrict effort, to close areas to fishing, and to manage by regulation of mesh sizes and seasons, but they were not satisfactory yet.

There is no regular forum where in the Yellow Sea fishing nations meet to discuss effective management of the fisheries. There is no adequate access of national researchers to the published literature of foreign colleagues within the region. It should be feasible to organize at least an exchange of publications among the principal researchers around the Yellow Sea. The level of scientific capacity among this c-astal states is getting higher.

National fisheries regulations vary widely and are designed primarily to protect spawning grounds and larval and juvenile fish. So far none of the bilateral agreements cover the entire Yellow Sea resources, even though there exist two bilateral agreements between the Republic of Korea and Japan and between China and Japan.

At present each nation has some detailed data such as, age compositions, mortality, growth and reproduction, in conducting stock assesment for extremely selected species such as, small yellow croaker and mackerel, but for most fish stocks there are not enough data or information, even the data collection system is not established for some species. In addition to this scientific names are not standardized among the nations (Zhang *et al*, 1988).

Within the context of the LME concept, much could be achieved with well-organized, comprehensive surveys and analyses by participating nations and research institutions. Based on the knowledge obtained from the YSLME, an effective fisheries management scheme could be possibly developed on the basis of mutual benefits among nations in the near future.

REFERENCES

Aiken, J., G. F. Moore, and F. M. Holligan. 1992. Remote sensing of oceanic biology in relation to global climate change. J. Phycol., 28 : 579-590.

Chikuni, S. 1985. The Fish Resources of the Northwest Pacific. FAO Fisheries Tech. Pap. 266, Rome.

Choe, S. 1967. Phytoplankton studies in Korean water. II. Phytoplankton in the coastal waters of Korea. J. Oceanol. Soc. Kor., 2(1-2) : 1-12.

Falkowski, P. G., R. M. Park, Y. C. Kim, Y. C. Lee, S. K. Son, and H. J. Hwang. 1988. The study on the biological productivity of the fishing ground in the western coastal area of Korea, Yellow Sea. Bull. Nat. Fish. Res. Dev. Agency, 42 : 143-168.

Han, B. S., and J. K. Choi. 1991. A study on the environmental conditions of phytoplankton ecology in the tidal front area of the Yellow Sea. Yellow Sea Res. 4 : 39-56.

Kirk, J. T. O. 1983. Light and photosynthesis in aquatic.. ecosystems. Cambridge University Press, 401pp.

KORDI. 1990a Natural Resources Damage Assessment Model for Marine Environment(II). KORDI Report, BS-PG 00100-310-6.

KORDI. 1990b. A study on the coastal Water Pollution and Monitoring (III).

KORDI Report, BSPG 0012-315-4.

Liu, J. Y. 1990. Studies on marine ecology of the Yellow Sea in China. Yellow Sea Res. 3 : 45-71.

Liu, X. 1979. Status of fishery resources in the Bohai and Yellow Sea. In Fishing Resources Paper. 26 : 1-17 (in Chinese).

Nishimura, S. 1983. Okhotsk Sea, Japan Sea, East China Sea. In estuaries and enclosed seas. Ed. E. Ketum. Elsevier : 375-401.

Peterson. B. J. 1980. Aquatic primary productivity and the $^{14}C-Co_2$ method : a history of the productivity problem. Ann. Rev. Ecol. Syst. 11 : 359-385.

Tang, Q. 1989. Changes in the Biomass of the Yellow Sea Ecosystem in Biomass Yields and Geography of Large Marine Ecosystems. K. Sherman and L. M. Alexander, eds. Westview Press, USA.

Xio, S, 1960. Fisheries of the Bohai Sea, Yellow Sea, and East China Sea. In Marine Fisheries Resources Paper. 2 : 73-94 (in Chinese).

Yu, H. 1991. Marine fishery management in PR China. Marine Policy, January : 23-32.

Zhang, C. I., J. M. Kim and H. T. Huh. 1988. Current status of fisheries resources and their rational management in the Yellow and East China Seas. P. 71~96. In Y. B. Go, ed. Proceedings of Symposium on Development of Marine Resources and International Cooperation in the Yellow Sea and the East China Sea. Oct. 19-22. Cheju, Korea.

Zhang, C. I. and S. Yoo. 1994. Population dynamics and stock assessment of small yellow croaker, *Pseudosciaena polyactis* in Korean waters. Proceedings of the Worid Fisheries Congress.

Zhang, C. I., Y. M. Kim, S. Yoo, C. K. Kim, and S. M. Ahn. 1992a. A study on fluctuations in biomass of small yellow croaker, *Pseudosciaena polyactis* off Korea. Bull. Korean Fish. Soc. 25(1) : 37-44.

Zhang, C. I., S. Kim and S. B. Yoon. 1992b. Stock assessment and management implications of small yellow croaker in Korean waters. Bull. Korean Fish. Soc. 25(4) : 282-290.