한국해양환경공학회지
Journal of the Korean Society
for Marine Environmental Engineering
Vol. 13, No. 4. pp. 305-312, November 2010

중국 북부 연안의 잘피: 역사적 감소추세 및 현황에 대한 사례

장쑤에레이[†] · 리얀 · 리우핑 · 순핑 · 왕샤오 · 판시량 · 쑤퀸쳉
중국 해양부 제일 해양연구소

Seagrasses in Northern Chinese Seas: Historical Declines and Case Study of the Status

Xuelei Zhang[†], Yan Li, Ping Liu, Ping Sun, Xiao Wang, Shiliang Fan and Qinzeng Xu
Center for Marine Ecology Research, First Institute of Oceanography, State Oceanic Administration, 6 Xianxialing Road, Hi-tech Industrial Zone, Qingdao 266061, China

요　약

잘피밭은 많은 생태계서비스를 제공하는 경제적 가치가 매우 높은 연안습지의 한 종류다. 중국에서도 북부연안을 따라 넓은 잘피밭이 분포하나 오랫동안 중요성이 간과되어 왔고 연구도 부족한 실정이다. 본 논문은 최초로 중국 북부연안 잘피의 종류와 분포를 제시하였으며, 과거로부터 현재까지의 변동양상을 기술하여 역사적인 감소추세를 분포와 생물량의 관점에서 기술하였다. 대표적인 잘피밭의 현황을 나타내기 위해 추다오 지역을 선정하여 사례를 제시하였다. 환경조건이 좋은 곳에서는 잘피도 회복되고 있으며, 잘피밭에 의존하는 플랑크톤과 어류, 돌고래 등 해양포유류도 풍부하였다. 역사적인 감소추세와 현상황에 대한 원인이 토의되었으며 보호를 위하여 필요한 연구내용을 제시하였다.

Abstract – Seagrass beds are a type of coastal wetland with many ecosystem services and precious economic values. Seagrass meadows used to be widespread along the coasts in northern Chinese seas, yet they have long been overlooked and lack devoted study on their history and status. This paper firstly reveals, by synthesis of information on composition of seagrass species and their distribution, that the seagrasses in this region have experienced considerable declines, both in terms of distribution and biomass, from the earliest record to present days. Then, a case study at the seagrass bed of Chudao is described to show the status of representative seagrass meadows. The results indicate that the environmental condition is good, seagrasses are in recovery, the planktoners are healthy and rich fishery resources and the mammal finless porpoise are associated with the seagrass bed. The cause(s) of historical seagrass decline and current conditions are also discussed, and future recommendations on seagrass protection and mapping are suggested.

Keywords: Seagrass beds(잘피밭), Distribution(분포), Historical trends(역사적 추세), Northern Chinese coast (중국 북부연안)

1. INTRODUCTION

Seagrass beds are a type of coastal wetland with great economic value that provides many ecosystem services. However pressures from the increasing demography, economic growth and climate change are threatening the health of this habitat. It is reported that measured seagrass area has declined by 1.5% yr^{-1} on average (totally making 29% of the maximum area) since 1879 and the total global loss is estimated to 51000 km^2, the decline occurs in all areas with quantitative data available and the rate of decline has increased (Waycott et al. [2009]). We still lack data of the seagrass meadows in China, but there is common perception that these seagrasses are facing the same issues at least at the same extent.

[†]Corresponding author: zhangxl@fio.org.cn
This paper was selected and reviewed for publication from the International Symposium on East Asian Coastal Wetlands, Ramsar COP 10, 2008

In northern Chinese seas, seagrass meadows used to be widespread along the coast of the Yellow Sea and Bohai Sea (Yang [1979]). These seagrasses benefit the local (or even wider) human society through the biodiversity they supports, food production, income yield, jobs and folk culture (seagrass roofed folk houses and related life style, Liu [2008]). It was noted that local production of the valuable sea cucumbers was closely and positively related with condition of the seagrass meadows (Xia [1991]). Nonetheless, no study has traced these meadows' evolution (Han and Shi [2008]), nor studied their biodiversity. In a recent study supported by the UNDP/GEF Project "Reducing Environmental Stress in the Yellow Sea Large Marine Ecosystem", synthesis of limited data indicates that these seagrass beds have declined significantly - now mainly scatter in the coast of Shandong Province, among which the seagrass beds off Rongcheng City is ranked as one of the most representative coastal wetlands on the west bank of Yellow Sea (Zhang [2009]). Here we report the major findings on seagrass beds' history and status in this study.

2. MATERIALS AND METHODS

Literature reviews and on site visit and interviews were used to tackle historical changes of the seagrass meadows in China seas north of 35ºN latitude. To understand current condition, surveys were conducted at one of the most representative seagrass bed at Chudao (Fig. 1) in August (summer) and December (winter) 2008.

Samples for nutrients, chlorophyll a (chla) and plankton were collected at high tidal levels and analyzed with standard methods (GAQSIQ [2007]). Seagrass was sampled by hand during neap low tide in the subtidal stations at I2, I3, I4 (each sample area 0.1 m^2) and in the intertidal zone south of I2 (sample area 0.03 m^2), washed with tap water and oven dried at 60 ºC. A series of benthic trap nets (Fig. 1) of local design were deployed at the seagrass bed during four tides at each sampling station for a day to collect more information on finfish and other commercial organisms. Fixed zooplankton, seagrass and finfish samples was weighed on electronic scales.

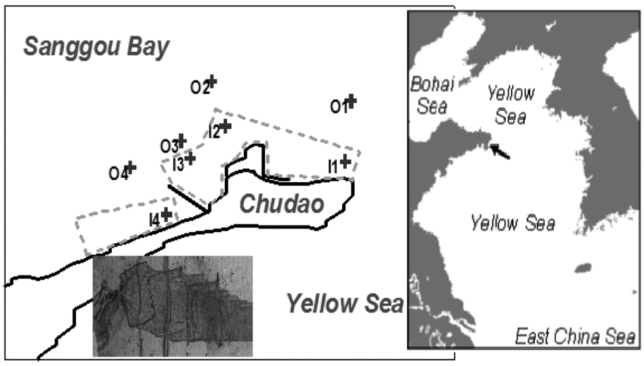

Fig. 1. Sampling sites (cross) at the seagrass bed (within dashed lines) at Chudao. Right insert shows the location (arrow) and lower insert shows the benthic trap net used.

Two-way ANOVA tests (Zar 1984), with factors of season and location (inside or outside the seagrass bed) were done for the data except for finfish data with One-way ANOVA test (Zar [1984]) with location as the factor. The composition of phytoplankton, zooplankton and finfishes inside/outside target areas over seasons was compared for similarity and non-metric multidimensional plots (nMDS) were employed to help interpret the results with the Primer 5.0 software.

3. RESULTS

3.1 Species composition and historical changes of the seagrass beds

The seagrasses in northern China seas belong to the Temperate Pacific flora. Seven seagrass species have been recorded in this region: *Zostera marina*, *Zostera caespitosa*, *Zostera japonica*, *Phyllospadix iwatensis*, *Phyllospadix japonicus* and *Ruppia maritime*, where the former five species are from the subfamily Zosteraceae and the last from Ruppiaceae. Among these, *Z. caespitose* only occurred in the early record (Yang [1979]), *R. maritime* occurs in shrimp pond (Xia [1991]) and possibly an introduced species, others have been referred (sometimes collectively) till present (Yang [1979], Bao [1991], Xia [1991], Yang [1984], Liu *et al.* [1998]).

Zostera spp. and *Phyllospadix* spp. are the dominant seagrass species. Meadows of *Zostera* spp. used to exist along the entire coast of the northern seas and *Phyllospadix* spp. also widespread in coasts of the three Provinces, Shandong, Liaoning and Hebei (Fig. 2, Yang [1979]). In the 1980s, these meadows largely declined and were limited to the coasts of Shandong and Liaoning Provinces (Fig. 2, Wang [1991], Xia [1991], Bao [1993]), and current meadows are only significant off Rongcheng, the eastern end of Shandong Penisular (Fig. 2).

The seagrass meadows have declined not only by geographical distribution, but also in covering areas and biomass. The few measurements of the seagrass meadows shown that the original 20000 Mu (13 km^2) of meadow in Laizhou Bay (Xia [1991]) largely disappeared and the upper depth margin moved from 1-2m to 4-5m (Ye and Zhao [2002]). The > 6500 Mu (4.3 km^2) of meadows in two bays off Rongcheng in 1980s (Xia

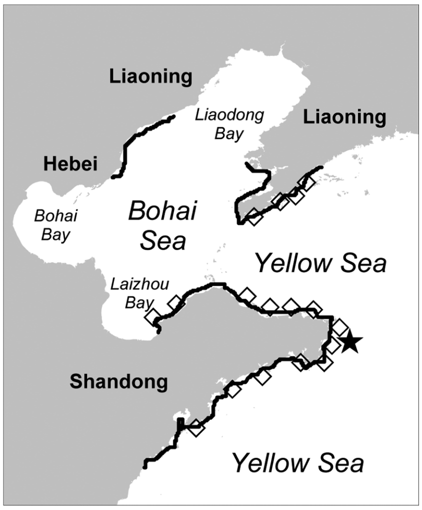

Fig. 2. Historical changes of seagrass locations in northern seas of China. The entire coastal line shown: *Zostera* spp. in the 1970s-, thick line: *Phyllospadix* spp. in the 1970s-, diamond: *Zostera* spp. and *Phyllospadix* spp. in the 1980s, star: current major seagrasse beds. Redrawn after Yang (1979), enriched with data of Wang (1991), Xia (1991), Bao (1993) and the author.

[1991]) has mostly been lost, with only ca. 1 km^2 remaining. The dry biomass ranged from 920 g/m^2 (*Zostera caespitosa*), 1200 g/m^2 (*Zostera marina*) to 1481 g/m^2 (*Phyllospadix iwatensis*) along the coast of Shandong in the 1950s-1970s (Yang and Wu [1981]), but in the 1980s these had declined to 200-550 g/m^2 for the mixed meadows of *Zostera* spp. and *Phyllospadix* spp. off Rongcheng (Xia [1991]).

3.2 Condition of the seagrass bed at Chudao

The coastal line along the seagrass bed of Chudao has remained relatively unchanged over decades, in contrast to many of the adjacent areas where reclamation and human development has modified the coastal morphology. Inside the seagrass bed, there is a small scale sea ranching using the benthic propagation of sea cucumber and clam while surrounding the beds there is a huge area of suspension culture of kelp, oysters and finfishes.

During the sampling seasons, water depth was shallow (<5 m) inside the seagrass bed and deeper outside the bed (4-13 m). The seabed is of sandy-muddy sediment and interspersed with a rocky reef.

Seawater temperature changed significantly with season (22-24 ºC in August and 5-7 ºC in December) but uniform across sampling sites. Salinity (30-32) was stable across the site through the seasons. Water transparency in summer (2 m) was slightly higher than in winter (1.4 m), but similar between inside and outside of the seagrass bed.

Seagrass (*Zostera marina*) distribution was abundant but patchy across the sampling sites inside the bed. Seagrass biomass (above ground dry weight) in summer was 750±930 kg/m^2 (mean±sd, max at 2100 g/m^2) and shoot density was 424±431 shoots/m^2 (mean±sd, max at 1050 shoots/m^2), generally correlated with its biomass. Seagrass shoot height averaged 90 cm, with max height at 118 cm. The seagrass at I2 presented lowest biomass but highest shoot length (118 cm), at low tidal zone presented highest biomass (2.1 kg/m^2) but lowest shoot length. The seagrass leaves were often fouled by epibionts (algae, bryozoans, snails, etc) that is less abundant only at the site I2. No reproductive shoot was found, indicating that the reproduction season (June-July) has just passed. In winter, the seagrass largely lost their above ground shoots and no effort was made to sample in this season.

In summer, nutrient levels were slightly lower inside the seagrass bed, while in autumn these were slightly higher inside the bed (Fig. 3). Nitrogen (DIN) concentration were higher in summer, while phosphate and silicate levels rose in winter, resulting in higher N/P and N/Si molar ratios in summer. All three

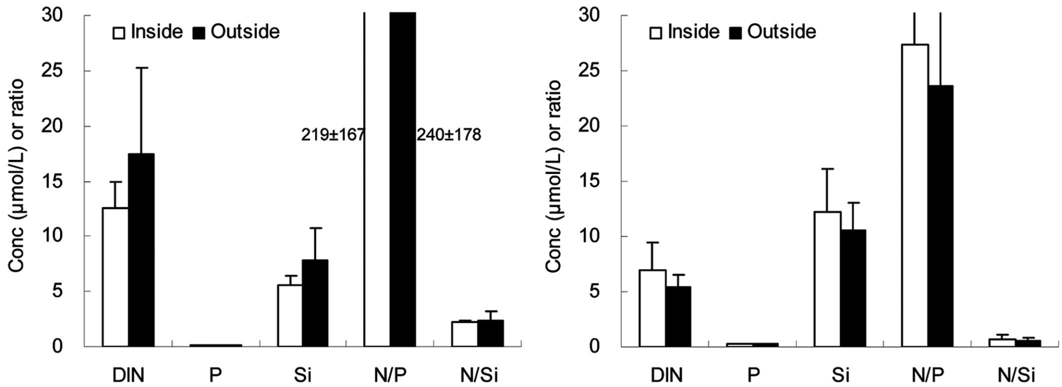

Fig. 3. Nutrient contents and molar ratios inside and outside the seagrass bed at Chudao in summer (left panel) and autumn (right panel).

Table 1. ANOVA analysis of nutrient concentrations' association for the factors of season, location and their interaction at the Chudao seagrass bed

		DIN			P			Si		
Factors	df	MS	F	p	MS	F	p	MS	F	p
Season	1	308.011	16.755	0.001	0.085	19.098	0.001	88.200	13.445	0.003
Location	1	11.815	0.643	0.438	8×10^{-5}	0.020	0.890	0.209	0.032	0.861
Season × Location	1	41.002	2.230	0.161	0.001	0.134	0.721	14.869	2.266	0.158
Error	12	18.834			0.004			6.560		

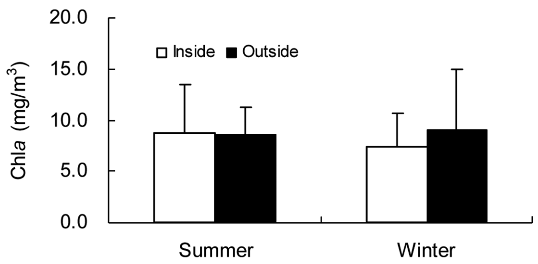

Fig. 4. Chlorophyll *a* contents inside and outside the seagrass bed at Chudao.

nutrients were significantly affected by seasonal change but not whether the samples were taken in side or outside the seagrass area (Table 1).

Chlorophyll *a* (chl*a*) content (7~9 mg/m^3) showed minor changes with seasons and between the inside and outside of the seagrass bed, but larger differences (standard deviation 3~6 mg/m^3) within either parts (Fig. 4). The chl*a* levels were generally in accordance with high phytoplankton abundance, 3.3×10^8 cell/m^3 (summer) and 4×10^8 cell/m^3 (winter) inside the bed and 6.6×10^8 cell/m^3 (summer) and 0.9×10^8 cell/m^3 (winter) outside the bed. Larger species (sampled by the 70 m-mesh net) made a small fraction (0.06~2%) in phytoplankton abundance. No significant difference was detected for seasonal or spatial change ($p>0.05$, Two-way ANOVA).

A total of twenty-six phytoplankton species were identified in the summer samples and twenty-seven in winter, of which fifteen (summer) and nineteen (winter) occurred inside the seagass bed while twenty-two (summer) and twenty-three (winter) occurred outside the bed. Diatoms were dominant both by species number and abundance in the phytoplankton, while dinoflagellate species only significantly contributing to cell abundance in winter, up to 17% inside the bed and 9% outside the bed. The most dominant phytoplankton species was the diatom, *S. costatum* in summer and *Melosira* sp. in winter. Diversity (Shannon-Weiner's index, H') of phytoplankton was significantly different between inside and outside the bed (Table 2): H' inside the seagrass bed in summer (2.3) was higher than that outside the bed (1.4) but H' in winter (1.8) was lower than that outside the bed. Similarity was moderate (47-56) for the phytoplankton community inside vs. outside the seagrass bed at both seasons but low (32) between summer and winter community, as shown in the nMDS feature (Fig. 5).

There were twenty-five zooplankton species/groups in summer and twenty in winter, of which twenty-one (summer) and sixteen (winter) occurred inside the seagrass bed while twenty-two (summer) and fourteen (winter) occurred outside the seagrass bed. In both seasons zooplankton mainly consisted of copepods and invertebrate larvae by species number and by abundance. One jellyfish species was present inside the seagrass bed in either season. Fish eggs/larvae (*Cynoglossus* sp. egg and *Rhinogobius* sp. larvae) were observed at very low densities (<0.5 inds/m^3) only inside the seagrass bed through

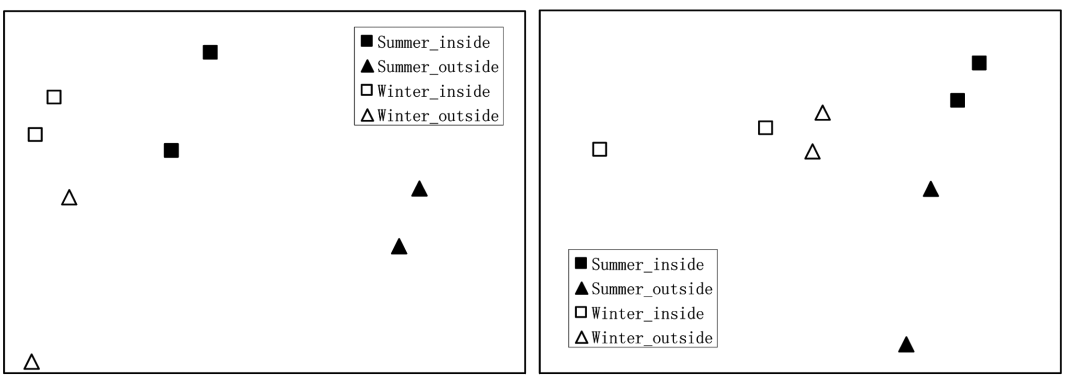

Fig. 5. nMDS plots (stress 0.01) applied to abundance of phytoplankton (left panel) and zooplankton (right panel) at the seagrass bed at Chudao.

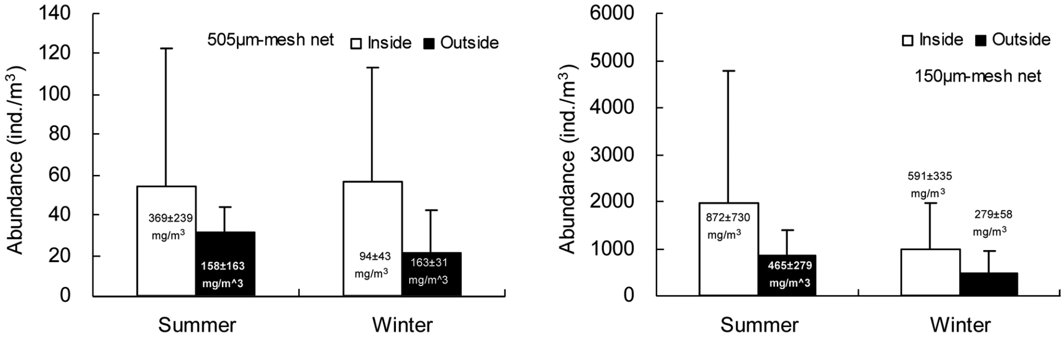

Fig. 6. Abundance and wet biomass of zooplankton in two types of nets inside and outside the seagrass bed at Chudao.

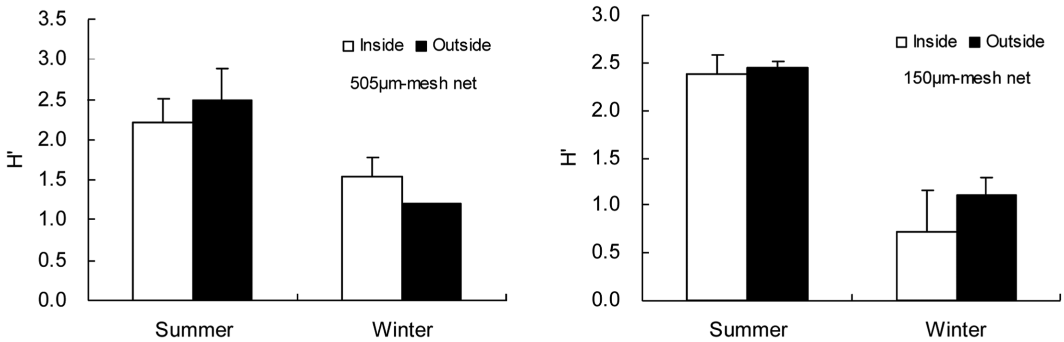

Fig. 7. Diversity (H') of zooplankton in two types of nets inside and outside the seagrass bed at Chudao.

both seasons. Similarity was moderate (60) for zooplankton in 150 m-mesh nets inside vs. outside the seagrass bed in summer and for those in 505 m-mesh nets between summer and winter, otherwise similarity was low (<30) as shown in the nMDS feature (Fig. 5).

Zooplankton abundance inside the seagrass bed was higher than that outside the bed and abundance was similar (505 m-mesh net samples) or slightly decreased (150 m-mesh net samples) between summer and winter (Fig. 6). Biomass generally followed that of abundance except in winter biomass of 505 m-mesh net samples inside the bed was lower than outside (Fig. 7). Diversity index (H') values were higher in summer (1.2~2.6); those inside the seagrass bed were similar with (in summer), higher (505 m-mesh net samples in winter) or lower (150 m-mesh net samples in winter) than those outside the seagrass bed (Fig. 7). Apart from the biomass of zooplankton in 505 m-mesh nets due to season and location interaction and 150 m sample diversity between summer and winter (both $p<0.05$, Table 2), no other significant difference was detected for zooplankton abundance, biomass or diversity due to effect of season or location ($p>0.05$, Two-way ANOVA).

The captures of benthic trap nets mainly consisted of finfish species (*Larimichthys polyactic*, *Hexagrammos otakii*, *Lateolabrax japonicus*, *Sebastes schlegeli*, *Paralichthys olivaceus*, *Kareius bicoloratus*, *Cleisthenes herzensteini*, *Astroconger myriaster*), also with the conch (*Rapana* sp.), sea cucumber (*Apostichopus japonicus*) and crab (*Charybdis japonica*). The total quantity and volume of these organisms in the trap capture was relatively high compared with catches reported by fishermen from adjacent coastal waters, and catches inside the seagrass bed were higher than those from outside (Fig. 8) although only biomass difference was statistically significant ($F=7.227$, $p=0.036$,

Table 2. ANOVA analysis of plankton diversity indices' and zooplankton biomass' association for the factors of season, location and their interaction at the Chudao seagrass bed.

		H'-phytoplankton			H'-150 μm zooplankton			Biomass-505 μm zooplankton		
Factors	df	MS	F	p	MS	F	p	MS	F	p
Season(S)	1	0.241	6.088	0.090	2.783	35.371	0.010	73577	4.587	0.053
Location(L)	1	0.787	19.906	0.021	0.005	0.059	0.823	20093	1.253	0.285
S×L	1	-			-			78260	4.879	0.047
Error	12	0.040			0.079			16040		

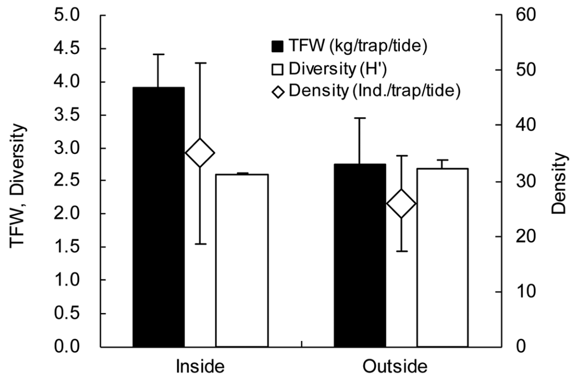

Fig. 8. Biomass, abundance and diversity (H') of animals captured by benthic trap nets deployed inside and outside the seagrass bed at Chudao.

One-way ANOVA), while diversity was same for the captured animals inside and outside the seagrass bed (p>0.05, One-way ANOVA). The similarity between finfish capture composition was high (84) between inside and outside the bed.

During the survey in summer, we saw a small cohort of finless porpoise *Neomeris phocacenoides sunameri* and local fishermen said these animals (both adult and young) could be seen year round.

4. DISCUSSION

The review of historical changes indicated that seagrass meadows experienced significant declines in northern seas of China. The cause(s) to seagrass bed declines remains unresolved, as pointed that seagrass losses could be attributed to a broad spectrum of anthropogenic and natural causes (Orth *et al.* [2006]). We propose that these seagrass losses were firstly due to large scale reclamation and degradation of the sea quality, followed by local scale mechanism(s) associated with intensive culture, which might result in accumulation of detrimental organics (e.g. polyphenols from the brown kelp) that are harmful to seagrasses and fine sediments (biodeposit from the shellfishes) that are easily resuspended causing decreased water transparency which was also identified as the major cause of decline and failure of recovery of *Z. marina* in the Dutch Wadden Sea (Giesen *et al*. [1990]). We found all the shallow water seagrass samples covered a thin silt mat, which alerts the risk of "wasting disease" (Vergeer and den Hartog [1991]).

This study also reveals that current seagrass biomass is ca. 0.30 kg/m^2 subtidal and 2.1 kg/m^2 in low tidal zone at Chudao. This indicates a variable (slight subtidally to moderate in low tidal zone) recovery of seagrass, comparing with that of 0.2-0.5 kg/m^2 in 1980s (Xia [1991]) and 0.9-1.5 kg/m^2 of the earliest record (Yang and Wu [1981]) in this region. Although the cause(s) of such recovery are still not clear, actions are suggested to protect the current seagrass meadows and promote their healthy, quick development from threats such as improper engineering works, over-intensive longline suspended aquaculture and removal for short term transplantation as shelter in pond cultures. In common with seagrasses worldwide, the meadows in the study region are experiencing all five of the most serious threats to marine biodiversity: overexploitation, physical modification, nutrient and sediment pollution, introduction of alien species, and global climate change (Norse [1993]). Potential threats being faced by the seagrass beds in northern seas of China include: fast development of intensive longline culture, transplantation of seagrass to shrimp ponds for temporary use, weak awareness of the seagrass values amongst the younger generation, and lack of clear and powerful conservation mechanism(s) from the government. The seagrass meadows might be easily destroyed and lose their values if we do not take right measures in time.

At the Chudao seagrass bed, both nitrogen (DIN) and phosphate concentrations were below Type IV seawater standard (GAQSIQ [1997]) across the seasons, which together with water transparency and abundance of the plankton was consistent with an earlier study over the last decade (Zhang [2003]), indicating a good quality of the seawater in this area. Nutrients levels inside the seagrass bed were slightly lower in summer (active growth) and higher in winter (innate season) than outside indicates that seagrass growth may further help maintain the nutrient levels. The lack of significant differences in most parameters (nutrients, chl *a*, and zooplankton) measured inside and outside the seagrass probably reflects the tidal flushing of the seagrass beds that would result in mixing of both sampled waters.

The high levels of chl*a* around the seagrass bed was normal and not associated with red tides, because during the sampling time seawater colour, transparency, pH (8.0 in summer and 8.3 in winter) and phytoplankton diversity (*H'*=2.0) were all normal, no harmful algal species abundance reached a bloom level, and abundant fishes occurred to be healthy during the trial captures. Breakages from the seagrass leaves (in summer) and cultivated kelps, however, might contribute to the high chl*a* levels to certain extent. The rich finfish resources might also help maintain high phytoplankton biomass through top-down control of algal grazers - the zooplankton - and releasing the pressure on ,microalgae. However, the high chl*a* concentrations and the high biomass of fisheries resources found in the seagrass beds, suggests this is a highly productive habitat, and this productivity may spill over to surrounding areas.

The rich fishery resources (adults, eggs and larvae) not only benefit local human society by provisioning, providing services (e.g. food), but also helps maintain a healthy system through regulation services. The former is straightforward: almost all the species captured in the sample traps were important local commercial species; the seagrass bed is also an ideal releasing ground, and is being utilized in this way for commercial benthic organisms such as sea cucumber and clams. The fishery resources also help maintain zooplankton populations at moderate levels, so that no red tides occurred even though the sea is productive. The relatively rich fishery resources adjacent to the seagrass bed may also indicate a possible spillover effect of the seagrass bed on local fish community, which also builds at other marine protected areas (Stobart *et al.* [2009]). The presence of eggs and larvae inside the sea grass suggests that this habitat may act as spawning ground and nursery for some species in common with numerous other studies (e.g. Jelbart *et al.* [2007], Laurel *et al*. [2007]).

5. CONCLUSION AND RECOMMENDATIONS

The seagrass bed is a coastal wetland habitat with many values and functions. The seagrass meadows have experienced considerable decline, but their gradual recovery requires protection and promotion actions, which includes and is not limited to: maintenance of the water transparency and other environmental conditions to ensure the seagrasses' ability to growth, protection from reclamation, the adverse impacts of aquaculture and its use as a seedling supply area for artificial restoration projects in other areas. A more precise mapping of the seagrass distribution in the area is in need to help assess the potential of biodiversity they host, which depends largely on seagrass complexity (Jelbart *et al.* [2007]), and the map can also be used to help design a recovery plan and guide monitoring of the meadows' condition.

ACKNOWLEDGEMENT

This study was supported with grants from the China MOST Project "Study and Demo of Key Techniques for Restoration of Damaged Typical Habitats in the Important Embayment Coastal Zone" (No. 2010BAC68B01) and the UNDP/GEF Project "Reducing Environmental Stress in the Yellow Sea Large Marine Ecosystem" (Contract No. O2-B-2108_Bio_specialist). The authors wish to thank Dr. Mark Walton for his valuable comments on the manuscript draft. ZXL is grateful to the Getbol Forum's invitation to present at the International Symposium on East Asian Coastal Wetlands at Changwon, Korea, October 27, 2008.

REFERENCES

[1] Bao, Y.E., 1993, The Bays of China: Vol.1. The East of Liaodong Peninsula, Beijing: Ocean Press of China. 338pp (in Chinese).

[2] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (GAQSIQ), 2007, GB/T 12763 - Specifications for Oceanographic Survey, Beijing: Standards Press of China (in Chinese).

[3] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (GAQSIQ), 1997, GB 3097 - Sea Water Quality Standard. Beijing: Standards Press of China (in Chinese).

[4] Giesen, W.B.J.T., van Katwijk, M.M., den Hartog, C., 1990, Eelgrass condition and turbidity in the Dutch Wadden Sea, Aquat. Bot., Vol.37, 71-85.

[5] Han, Q.Y. and Shi, P., 2008, Progress in the study of seagrass ecology, Acta Ecologica Sinica, Vol.28, No.11, 5561-5570 (in Chinese with English abstract).

[6] Jelbart, J.E., Ross, P.M. and Connolly, R.M., 2007, Patterns of small fish distributions in seagrass beds in a temperate Australian estuary, J. Mar. Biol. Ass. U.K., Vol.87, 1297-1307.

[7] Laurel, B.J., Stoner, A.W., Ryer, C.H., Hurst, T.P., Abookire, A.A., 2007, Comparative habitat associations in juvenile Pacific cod and other gadids using seines, baited cameras and laboratory techniques, J Exp Mar Biol Ecol, Vol.351, 42-55.

[8] Liu, Z.G., Visiting The Rare Folk Houses in China - Seagrass Roofed Houses, Beijing: Ocean Press. 201pp (in Chinese).

[9] Liu, Z.H., Dong, S.G., Mu, H.J., Yang, Y.J. and Gao, M.J., 1998, Investigation of genetic diversity in *Zostera marina* Linn. from Huiquan Bay of Qingdao. Marine Fisheries Research (China), Vol.19, No.2, 27-32 (in Chinese with English abstract).

[10] Norse, E.A. (ed.), 1993, Global Marine Biological Diversity: A Strategy for Building Conservation into Decision Making, Washington, DC: Island Press, 383pp.

[11] Orth, R.J., Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Jr Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Olyarnik, S., Short, F.T., Waycott, M., Williams, S.L., 2006, A global crisis for seagrass ecosystems, Bioscience, 56, 987-996.

[12] Stobart, B., Warwick, R., González, C., Malloll, S., Díazl, D., Reñones, O., Goñi, R., 2009, Long-term and spillover effects of a marine protected area on an exploited fish community, Mar Ecol Prog Ser, Vol.384, 47-60.

[13] Vergeer, L.H.T. and den Hartog, C., 1991, Occurrence of wasting disease in *Zostera noltii*, Aquat Bot, Vol.40, 155-163.

[14] Wang, W.H. (chief ed.), 1991, The Bays of China: Vol.4. The South of Shangdong Peninsula and Jiangsu, Beijing: Ocean Press of China. 448pp (in Chinese).

[15] Waycott, M., Duarte, C.M., Carruthers, T.J.B., Orth, R.J., Dennison, W.C., Olyarnik, S., Calladine, A., Fourqurean, J.W., Jr Heck, K.L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Short, F.T., and Williams, S.L., 2009, Accelerating loss of seagrasses across the globe threatens coastal ecosystems, Proc. Natl. Acad. Sci. USA (doi. 10.1073/pnas.0905620106).

[16] Xia, D.X. (chief ed.), 1991, The Bays of China: Vol.3. The North and East to Shangdong Peninsula, Beijing: Ocean Press of China. 487pp (in Chinese).

[17] Yang, Z.D. and Wu, B.L., 1981, A preliminary study on the distribution, productivity, structure and functioning of sea-grass beds in China, Acta Ecologica Sinica, Vol.1, No.1, 84-89 (in Chinese with English abstract).

[18] Yang, Z.D., 1984, The studies on sea-grass beds and its epibionts in the Qingdao coast, Journal of Oceanography of Huanghai and Bohai Seas (China), Vol.2, No.2, 56-67 (in Chinese with English abstract).

[19] Yang, Z.D., 1979, The geographical distribution of sea-grass, Bulletin of Oceanology and Limnology (China), Vol.2, 41-46 (in Chinese with English abstract).

[20] Ye, C.J. and Zhao, K.F., 2002, Advances in the study on the marine higher plant eelgrass (*Zostera marina* L.) and its adaptation to submerged life in seawater, Chinese Bulletin of Botony, Vol.19, No.2, 184-193 (in Chinese with English abstract).

[21] Zar, J.H., 1989, Biostatistics Analysis, 2nd ed., New Jersey: Prentice-Hall International Inc., 700pp.

[22] Zhang, X.L., 2003, Feedback impacts between filter-feeding molluscs and their environment and carrying capacity of mariculture, Ocean University of China, doctor thesis (in Chinese with English abstract).

[23] Zhang, X.L., 2009, Habitat Classification, Selection and Assessment of Representative Habitats in the Yellow Sea Coast of China, UNDP/GEF Report.

2010년 8월 13일 원고접수
2010년 11월 20일 심사완료
2010년 11월 22일 수정본 채택