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ARTICLE

Long-Term Changes in Fish Assemblage Structure in the Yellow River Estuary Ecosystem, China

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Abstract

The Yellow River estuary ecosystem is an important spawning ground for many species found in the Bohai Sea and Yellow Sea and contributes substantially to the fishery resource structure and biological reproduction in the northern China Sea. Based on long-term ecosystem surveys in the Yellow River estuary during the main spawning period (May) of most fishery species from 1959 to 2011, the responses of the ecosystem, including regime shifts in species composition, biomass, diversity, and other related factors, were analyzed in this study. Since the 1980s, the dominant large-size species of high economic value (e.g., Largehead Hairtail *Trichiurus lepturus*) have been replaced by short-lived, low-trophic-level, planktivorous pelagic species (e.g., Scaly Hairfin Anchovy *Setipinna taty* and Japanese Anchovy *Engraulis japonicus*). Currently, traditional commercially targeted fishes, such as the Largehead Hairtail, Red Seabream *Pagrus major*, and Pacific Herring *Clupea pallasii*, are locally extinct. There has been a rapid shift of dominant species from highly valued, high-trophic-level, large-sized demersal species with complicated age structures to low-value, low-trophic-level, small-sized pelagic species with simple age structures; this shift has resulted in major changes to the ecological cycle and restoration of fishery resources. The fish catch declined from 421.66 kg/h in 1959 to 0.25 kg/h in 2008 and then increased to 3.62 kg/h in 2011. Diversity and evenness indices showed a continuously increasing trend during 1959–2011. The Yellow River estuary may be significantly compromised by overfishing, climate change, dam construction, and pollution, resulting in the decline of traditional fishing industries and reduced biodiversity in this ecosystem.

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Estuaries play an essential role as feeding, spawning, and breeding grounds for many fishes, including freshwater and marine species, and they are important for many resident estuarine species because they offer a favorable habitat and support the migratory routes for catadromous and anadromous species (Elliott and McLusky 2002; Martinho et al. 2007, 2008). However, estuarine ecosystems have been suffering from eutrophication, overfishing, climate change, and general environmental degradation (Martinho et al. 2008). Thus, several studies on ecosystem health have been conducted (James et al. 2008; Selleslagh et al. 2009; Nicolas et al. 2010), including long-term studies that are used to analyze trends in fish assemblages (Elliott et al. 2007; Purcell et al. 2010). Overfishing and climate change are increasingly threatening the world's marine ecosystems, and the effects of fishing on marine ecosystems worldwide have consequences for populations and communities (Pauly et al. 2002; Myers and Worm 2003; Jennings and Blanchard 2004). It is important to identify the dynamics of the fish community in response to climatic regime shifts and anthropogenic activities (Yasunaka and Hanawa 2002).

The Yellow River estuary ecosystem is a spawning zone for many commercial species of the Bohai Sea and Yellow Sea; it also constitutes the major fishing ground in the northern China Sea. In recent years, with a growing population and increasing economic development along the Bohai Sea coast, the Yellow River estuary ecosystem has greatly changed (Zhao et al. 2000), resulting in further impacts on the growth, survival, and reproduction of fishery species (Liu et al. 2003). These impacts, coupled with high fishing intensity—particularly the rapid development of bottom-trawl prawn fisheries—have led to an abundance of juveniles of commercial species in the catch. The demersal fisheries have declined, and due to high fishing intensity the major fishery stocks have changed through cascading trophic chain reactions, particularly regime shifts of dominant species and variations in individual size and age (Jin and Tang 1998; Jin and Deng 2000; Wang 2009). However, long-term variations in fish assemblage diversity and trophic spectrum structure in the Yellow River estuary ecosystem have not been fully addressed.

Fish assemblage diversity is the basis of survival and development for some societies, as fish supply high-quality protein and improve the dietary structure. Conservation of fish assemblage diversity is related to the future of sustainable development, so it is necessary to understand the processes and mechanisms of long-term variations in biodiversity. These variations are of worldwide concern, and the measures to be implemented in management initiatives aimed at sustainable fisheries and biodiversity conservation should be fully considered. Species composition and richness describe qualitative variations of fish species; biomass and productivity refer to the quantity and rate of production. Stability can refer to the temporal constancy of a community, resistance to environmental change, or resilience after a disturbance. Based on long-term fishery survey data collected in May (the spawning period for most of the Bohai Sea and Yellow Sea fish species that spawn in the Yellow River estuary), the present study involved analysis of variations in species composition and fish assemblage diversity, as well as trophic spectrum structure, stability, and related factors, over the past 50 years.

METHODS

Study Area and Field Sampling Procedures

The Yellow River estuary ecosystem (Figure 1) is located in the southern Bohai Sea (south to 38°50′N; 119°30′E to 120°30′E) and accounts for approximately 10% of the total Bohai Sea area. The estuary is characterized by a shallow-water shelf, where the water depth is less than 15 m, and the sediments are composed of soft mud and sand. The Yellow River estuary is an important ecological zone because the Yellow, Xiaoqing, Bailang, Guangli, Wei, and Jiaolai rivers enter the sea at this location. These rivers deliver abundant freshwater and terrestrial materials, such as sediment and nutrients, thereby providing resources for the high productivity in this area. The estuary forms the main spawning grounds and habitats for many commercial species of the Yellow Sea and Bohai Sea, such as the Small Yellow Croaker *Larimichthys polyactis*, Largehead Hairtail *Trichiurus lepturus*, Yellow Drum *Nibea albiflora*, and Red Seabream *Pagrus major*. The Yellow River estuary also supports the Bohai Sea fishing industry, supplying up to 40% of the Bohai Sea total catch. The coastal waters of the Yellow River estuary are bounded by a heavily urbanized area, the fluvial plain along the estuary is surrounded by agricultural land, and the freshwater from the Yellow River is greatly regulated by dams and rainfall.

In the present study, fish assemblage data were obtained from bottom-trawl surveys in May of 1959, 1982, 1993, 1998, 2003, 2008, and 2011 at 20 designated stations (Figure 1). Two trawlers (~200-hp vessels) were deployed for 1- or 2-h tows; CPUE was standardized to 1 h at each station (for fish species

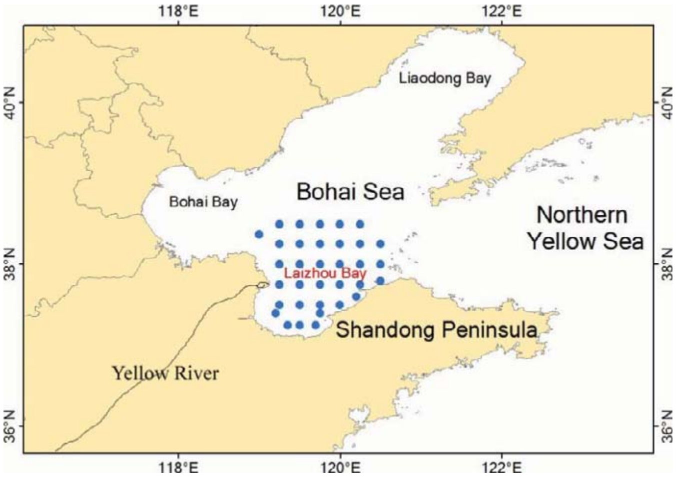

FIGURE 1. Sampling stations in the Yellow River estuary ecosystem.

only). All specimens were sorted at the species level and were counted and weighed on-board. Only fish were included in the analysis. The same net was used for all sampling; the mesh size for the net opening was 6.3 cm, the depth of the net opening was 6 m, the width of the net opening was 22.6 m, the mesh size of the cod end was 2 cm, and the trawling speed was approximately 4.82 km/h (2.6 knots). During each sampling cruise, duplicate water samples were collected to measure water temperature (with a reversal thermometer) and salinity (with an induction salinometer).

Data Analysis

Functional groups.—Functional groups were determined based on feeding habits and adult mobility (Bellwood et al. 2004; Micheli and Halpern 2005). The fish species in the Yellow River estuary were divided into eight functional groups: planktivores (G1), planktivores/benthivores (G2), benthivores (G3), benthivores/piscivores (G4), omnivores (G5), mobile piscivores (G6), elasmobranchs (G7), and roving piscivores (G8; Bellwood et al. 2004; Zhuang et al. 2006; Zhang et al. 2007; Jiang 2008).

Diversity indices.—The variation in fish species composition was examined by using cluster analysis based on the Bray–Curtis similarity matrix calculated from square-root-transformed biomass (kg/h) data (Clarke and Warwick 2001). Species richness was estimated with Margalef's richness index (R; Margalef 1958). The Shannon–Weaver diversity index (H'; Shannon and Weaver 1949) and Lande's index ($1 - \lambda$; Lande 1996) were used to assess species diversity. Pielou's evenness index (J'; Pielou 1975) was used to determine evenness. All of the biodiversity indices were calculated from relative biomass (kg/h).

Trophic category and mean trophic level index.—Fish species were stratified into five trophic categories (from planktivores to roving piscivores) based on trophic level and food habits: (1) trophic levels less than 3.0 (e.g., Dotted Gizzard Shad *Konosirus punctatus* and Redeye Mullet *Liza haematocheila*); (2) trophic levels $\geq$ 3.0 but less than 3.5 (e.g., Japanese Anchovy *Engraulis japonicus*, Scaly Hairfin Anchovy *Setipinna taty*, and Osbeck's Grenadier Anchovy *Coilia mystus*); (3) trophic levels $\geq$ 3.5 but less than 4.0 (e.g., Silver Pomfret *Pampus argenteus* and Marbled Flounder *Pseudopleuronectes yokohamae*); (4) trophic levels $\geq$ 4.0 but less than 4.5 (e.g., Fat Greenling *Hexagrammos otakii* and most of the flatfishes); and (5) trophic levels $\geq$ 4.5 but less than 5.0 (e.g., Japanese Seabass *Lateolabrax japonicus*, Monkfish *Lophius litulon* [also known as Yellow Goosefish], Mottled Skate *Raja pulchra*, and Mi-iuy Croaker *Miichthys miiuy*). Trophic level information for each species was based on the literature and prey analysis (Yang et al. 2001; Zhang 2005).

The mean trophic level (MTL) of fish landings can be used as an index of sustainability in exploited marine ecosystems (Pauly et al. 2002). The MTL for the fish community not only depended on the trophic level of each species but also reflected the proportion of biomass for each species. In the present study, the MTL of each fish community was estimated according to Tian et al. (2006),

$$\mathrm{MTL} = \sum_{i=1}^{n} \frac{\mathrm{TL}_i Y_i}{Y},$$

where Y_i represents the catch of species i in every sampling period, Y represents the sum of catch for the total number of species n in every sampling period; and TL_i is the trophic level for species i. The MTL values were compared with values from similar studies in the Bohai Sea (Yang et al. 2001; Zhang 2005).

Climatic and oceanographic indices.—The Southern Oscillation Index (SOI; www.bom.gov.au/climate/current/soihtm1.shtml), monthly sea surface temperature (SST) anomalies (www.coaps.fsu.edu/pub/JMA_SST_Index/), and warm and cold SST phases (www.coaps.fsu.edu/jma.shtml) were chosen as the climatic indices for the western Pacific Ocean. These indices were well documented and associated with interannual–interdecadal variability not only of atmospheric and oceanic conditions but also of marine ecosystems in the North Pacific (Beamish et al. 2000; Tian et al. 2004). Data on Yellow River runoff, sediments, and basinwide precipitation in each year were obtained from the Bulletin of Sediments and Runoff for the Yellow River (YRCC 1950–2009). The El Niño–Southern Oscillation (ENSO) events identified from the SOI and SST data correspond well with lows in annual water and sediment flux to the western Pacific Ocean, showing that climate oscillation dominates short-term (interannual) fluctuations in sediment flux and rainfall.

RESULTS

Species Composition and Dominant Species

In total, 77 fish species belonging to 33 families were collected in the Yellow River estuary ecosystem during 1959–2011. Eight fish species (10.4% of species) were collected during every sampling year. With the exception of the Silver Pomfret and Small Yellow Croaker, most of these eight species were pelagic fishes, including the Japanese Anchovy, Scaly Hairfin Anchovy, Smallhead Hairtail *Eupleurogrammus muticus*, Dotted Gizzard Shad, Madura Anchovy *Thryssa kammalensis*, and White Gunnel *Pholis fangi*. Species composition analysis indicated that for more than 99% of the total weight of fish catch, there were extreme changes in fish species composition during 1959–2011 (Table 1).

In 1959, fish catch mostly consisted of commercial species, such as the Largehead Hairtail, Small Yellow Croaker, Tongue Sole, Tiger Puffer, White Croaker, and Japanese Seabass. The Largehead Hairtail was the predominant species of the total catch, with a CPUE reaching 330.03 kg/h. The CPUE for the Small Yellow Croaker was 65.20 kg/h. The Largehead Hairtail and Small Yellow Croaker catches accounted for 93.9% of the

TABLE 1. Top-ten fish species composition (average catch [kg/h] and contribution to total fish catch [%]) for each sampling year in the Yellow River estuary ecosystem, 1959–2011.

	1959		1982		1993		1998		2003		2008		2011	
Species	kg/h	%	kg/h	%	kg/h	%	kg/h	%	kg/h	%	kg/h	%	kg/h	%
Largehead Hairtail *Trichiurus lepturus*	330.03	78.4			0.26	0.8								
Small Yellow Croaker *Larimichthys polyactis*	65.20	15.5			0.46	1.4			0.32	6.5	0.01	5.1	0.60	16.7
Tongue Sole *Cynoglossus semilaevis*	7.99	1.9					0.03	0.8						
Tiger Puffer *Fugu rubripes*	3.56	0.9											0.19	5.2
Bartail Flathead *Platycephalus indicus*	3.49	0.8					0.03	0.9	0.05	1.1				
White Croaker *Argyrosomus argentatus* (*Pennahia argentata*)	2.98	0.7												
Japanese Seabass *Lateolabrax japonicus*	1.17	0.3	6.57	4.2									0.79	21.8
Rayfish (Ocellate Spot Skate) *Raja porosa* (*Okamejei kenojei*)	0.93	0.2			0.63	1.9								
Silver Pomfret *Pampus argenteus*	0.68	0.2			0.23	0.7	0.16	4.7	0.35	7.1	0.07	29.2	0.23	6.4
Red Tonguesole *Cynoglossus joyneri*	0.67	0.2					0.04	1.1						
Finespot Goby *Chaeturichthys stigmatias*									0.08	1.6				
Bighead Croaker *Collichthys niveatus*			2.12	1.3										
White Gunnel *Pholis fangi*											0.02	7.2	0.19	5.3
Japanese Anchovy *Engraulis japonicus*			40.66	25.8	22.64	68.1	0.61	17.7			0.01	1.5		
Smallhead Hairtail *Eupleurogrammus muticus*							0.18	5.2	0.03	0.6	0.01	5.9		
Dotted Gizzard Shad *Konosirus punctatus*					0.88	2.7	0.32	9.3	0.05	1.1	0.01	4.1	0.04	1.0
Monkfish (Yellow Goosefish) *Lophius litulon*									0.05	1.0			0.25	6.8
Flathead Mullet (Striped Mullet) *Mugil cephalus*			1.75	1.1										
Bluefin Leatherjacket *Navodon septentrionalis*											0.02	9.3		
Yellow Drum *Nibea albiflora*			16.83	10.7										
Eel Goby *Odontamblyopus rubicundus*									0.08	1.5				
Olive Flounder *Paralichthys olivaceus*			1.62	1.0										
Marbled Flounder *Pseudopleuronectes yokohamae*			1.70	1.1										
Japanese Sardinella *Sardinella zunasi*			6.79	4.3	0.40	1.2								
Japanese Spanish Mackerel *Scomberomorus niphonius*					0.35	1.0					0.04	14.2		
Scaly Hairfin Anchovy *Setipinna taty*			67.21	42.7	2.45	7.4	0.57	16.5	2.28	46.1	0.03	13.0	0.64	17.8
Purple Puffer *Takifugu vermicularis*			4.21	2.7										
Madura Anchovy *Thryssa kammalensis*					4.05	12.2	1.20	35.0	1.57	31.7	0.01	4.0	0.43	11.8
Moustache Thryssa *Thryssa mystax*													0.04	1.1
Hound Needlefish *Tylosurus giganteus* (*Tylosurus crocodilus*)							0.07	1.9						
Total	416.70	99.0	149.46	94.8	32.35	97.7	3.21	93.1	4.86	98.3	0.23	93.5	3.40	93.9

total CPUE, whereas for other species the CPUE was below 10 kg/h and the catch was not above 2% of the total catch.

The dominant species in 1982 were mainly pelagic fishes; the Japanese Anchovy and Scaly Hairfin Anchovy were the most common species, accounting for 68.5% of the total catch. The Yellow Drum was also a dominant species. In 1993, the Japanese Anchovy, Madura Anchovy, and Scaly Hairfin Anchovy were the dominant species; the combined catch of the three species accounted for 87.7% of the total catch, but the CPUEs of these species had sharply declined in comparison with the CPUEs observed in 1982, particularly for the Scaly Hairfin Anchovy. The CPUE of Japanese Anchovy declined from 40.66 kg/h in 1982 to 22.64 kg/h in 1993; the CPUE of Scaly Hairfin Anchovy decreased from 67.21 kg/h in 1982 to 2.45 kg/h in 1993. In 1998, the CPUE for Madura Anchovy was greater than 1 kg/h, whereas the CPUEs for all other species did not exceed 1 kg/h; the dominant fishes were pelagic species.

In 2003, the CPUE was 2.28 kg/h for the Scaly Hairfin Anchovy and 1.57 kg/h for the Madura Anchovy; these two species accounted for 77.9% of the total catch. In 2008, the predominant fishes were pelagic species, including the Silver Pomfret, Japanese Spanish Mackerel, and Scaly Hairfin Anchovy; however, the CPUE was below 0.1 kg/h for each species. In 2011, the Japanese Anchovy and Madura Anchovy were the dominant species, and the Small Yellow Croaker and Japanese Seabass again were among the most common species in the catch, but CPUEs for all species were less than 1 kg/h and were equivalent to less than 1% of the CPUEs observed in 1959. During the study period (1959–2011), the CPUE of every species declined, most noticeably after 1998, when most of the species had CPUEs below 1 kg/h. The dominant species changed from large-sized commercial species in 1959 to small-sized pelagic species beginning in 1982. In addition, some Chondrichthyes species, such as the Rayfish (also known as the Ocellate Spot Skate) and Spotless Smooth-hound *Mustelus griseus*, were not observed during recent sampling years.

Dynamics in Abundance

Figure 2a represents the dynamics of fish catch and species composition in the Yellow River estuary ecosystem during 1959–2011. Average fish catch decreased from 1959 to 2008 and then increased from 2008 to 2011. The highest fish catch (421.66 kg/h) was obtained in 1959, and catch reached its lowest value (0.25 kg/h) in 2008. Demersal species were the main component of the fish catch structure in 1959, whereas in 1982 the percentage of demersal fish in the catch had greatly declined. Correspondingly, the proportion of pelagic fish in the total catch increased, peaking in 1993 and then stabilizing from 1998 to 2008. The contribution of demersal species to the total catch gradually increased after 1993; during 2011, the proportion of demersal fish in the total catch exceeded the proportion of pelagic fish.

Table 2 shows the family-level composition of the fish catch in the Yellow River estuary during 1959–2011. Engraulidae was the common dominant family in the fish catch during all sampling years (except 1959), particularly from 1982 to 2005. Engraulidae accounted for more than 50% of the total catch. Trichiuridae (78.4%) and Sciaenidae (16.3%) shared dominance in the fish catch composition during 1959, with lesser contributions from Cynoglossidae, Tetraodontidae, and Platycephalidae. In 1982, the fish catch mainly consisted of Engraulidae (68.6%) and Sciaenidae (12.8%), followed by Clupeidae, Percidae, and Tetraodontidae; other families contributed less than 2% of the total catch. In 1993, Engraulidae (87.7%) was the dominant fish family in the catch, followed by Clupeidae, Rajidae, Sciaenidae, and Trichiuridae. During 1998, Engraulidae (69.4%) and Clupeidae (9.9%) were the predominant families in the catch, followed by Trichiuridae and Stromateidae. In 2003, Engraulidae (78.5%) was again the dominant family represented in the total catch, followed by Stromateidae and Sciaenidae. During 2008, Stromateidae (29.8%), Engraulidae (18.8%), and Polynemidae (14.5%) were the dominant families in the total catch. The total catch in 2011 primarily included Engraulidae (30.9%), Percidae (21.8%), and Sciaenidae (16.9%) as the dominant families, along with contributions from Lophiidae and Stromateidae.

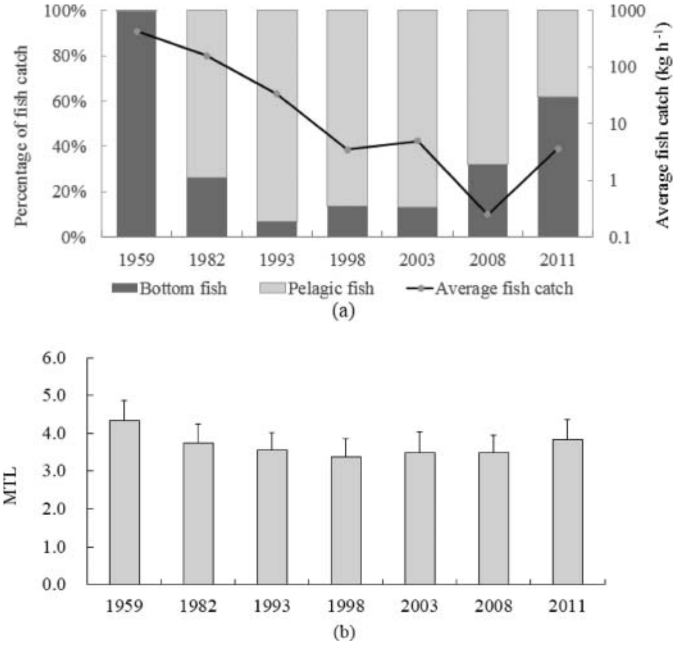

FIGURE 2. Dynamics of **(a)** the average fish catch and **(b)** the mean trophic level (MTL) of fish catch in the Yellow River estuary from 1959 to 2011.

Trophic and Community Structure

The MTL decreased from 1959 to 1998, increased slightly in 2003, maintained a stable level from 2003 to 2008, and then increased again in 2011 (Figure 2b). Figure 3 shows the trophic structure of the fish catch in the Yellow River estuary ecosystem. There were some differences among sampling years, so the fish catch at different trophic levels was calculated by using $\log_{10}$ transformed CPUE. In 1959, the fish catch was mainly

TABLE 2. Family-level composition of the fish catch (kg/h) in the Yellow River estuary ecosystem during 1959–2011.

Family	1959	1982	1993	1998	2003	2008	2011
Trichiuridae	330.06		0.47	0.18			
Engraulidae		108.06	29.14	2.38	3.88	0.05	1.12
Sciaenidae	68.69	20.10	0.61		0.32		0.61
Cynoglossidae	8.79	1.29					
Clupeidae		7.77	1.28	0.34			
Percidae	1.17	6.57					0.79
Tetraodontidae	3.56	4.51					
Platycephalidae	3.49	1.32					
Pleuronectidae		1.95					
Mugilidae		1.75					
Paralichthyidae		1.62					
Triglidae	1.38						
Stromateidae				0.16	0.35	0.07	0.23
Rajidae			0.63				
Lophiidae							0.25
Polynemidae						0.04	
Zoarcidae		1.12					
Other	3.74	1.53	1.10	0.37	0.39	0.09	0.62

distributed at trophic levels 3.5–4.5 (particularly 4.0–4.5), followed by 4.5–5.0; thus, the trophic level of the fish catch was relatively high in that sampling year. During 1982, the trophic level of the fish catch was also 3.5–4.5, but the most abundant trophic level was 3.5–4.0. In addition, fish from trophic levels lower than 3.5 accounted for a high proportion of the catch in 1982. Correspondingly, the proportion of the fish catch at trophic levels 4.0–5.0 decreased. In 1993, the fish catch representing trophic levels 3.0–4.5 showed a distribution pattern similar to that seen in 1982, but the catch from trophic levels less than 3.0 and greater than 4.5 decreased. In 1998, the fish catch greatly decreased, and the trophic level of the catch was mainly distributed at 3.0–4.0. During that year, the fish catch at trophic levels 4.0–4.5 decreased, and the fish catch representing trophic levels less than 3.0 and greater than 4.5 also decreased. In 2003 and 2008, the trophic level of the fish catch showed similar trends as were observed in 1998; however, in 2008, few individuals at trophic levels 4.5–5.0 were present in the catch. During 2011, the trophic level of the catch showed similar trends as in 1993, with fish being mainly distributed at trophic levels 3.0–4.5 (particularly 3.5–4.0).

The functional groups included the fish species with a total weight greater than 100 g in each survey, and functional groups were determined by feeding habits and the motility of adults. Table 3 shows the functional group structure of the fish catch from 1959 to 2011. In 1959, the fish catch by weight consisted primarily of G6, followed by G4 and G5; the observed fish species were mainly distributed in G1 and G4, followed by G6. Although G1 encompassed the highest number of species, the total catch weight contribution from G1 was just 1.0%. In 1982, the fish catch by weight consisted mainly of G1, followed by G5 and G2; however, the observed species were mainly distributed in G1, G2, and G3. During 1993, G1, G5, and G7 accounted for high proportions of the fish catch by weight; high numbers of species from G1, G3, and G6 were observed. In 1998, G1, G3, and G6 contributed high proportions of the catch weight; the percentage of observed species was highest for G1, G3, and G5. In 2003 and 2008, functional group distribution patterns showed a similar trend. Groups G1, G3, and G5 accounted for high proportions of the fish catch by weight as well as high percentages of the observed fish species. In 2011, the highest fish catch percentages by weight were from G1, G5, and G8; however, G1, G3, and G6 contributed the greatest numbers of species.

A cluster analysis dendrogram based on Bray–Curtis similarity in fish weight was used to assess similarity between sampling years (Figure 4). The similarity analysis indicated significant differences in the fish catch from 1959 to 2011. Excluding the 2008 sampling results, relatively high similarity in fish catch was detected between proximate sampling years. The greatest similarity was observed between the 2003 and 2011 fish catches, whereas the lowest similarity was found between fish catch in 1959 and catches observed during the other years.

Species Diversity

The total number of species in the fish community was an unambiguous index of species richness. The highest species number was observed in 1982, followed by 1998 and 1959; the lowest species number was found in 2008; and the species number in the other sampling years was relatively stable at

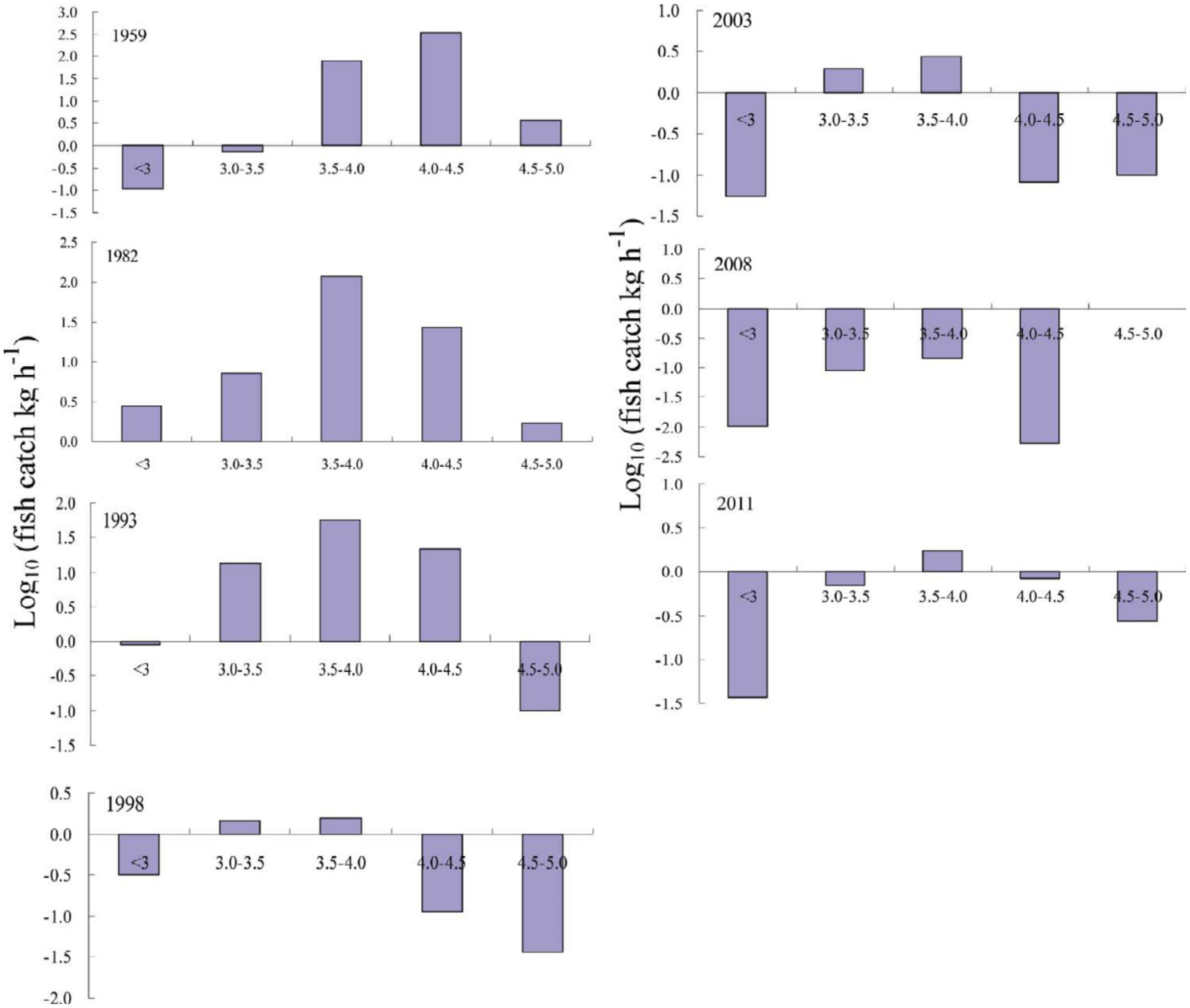

FIGURE 3. Trophic structure of the fish catch in the Yellow River estuary from 1959 to 2011 (*x*-axis labels indicate the trophic levels).

approximately 25 species. The number of families in the fish catch from 1959 to 2011 showed the same fluctuating trend as species number (Figure 5a). The indices H', $1 - \lambda$, J', and Margalef's R showed the comprehensive characteristics of the fish community's ecological diversity and heterogeneity. Margalef's R increased from 1959 to 1993, decreased through 2003, slightly increased in 2008, and exhibited another decrease in 2011. The value of J' slightly increased over the study period; however, H' and $1 - \lambda$ both showed a fluctuating, increasing trend from 1959 to 2011. The two diversity indices (H' and $1 - \lambda$) increased from 1959 to 1982, decreased in 1993, increased in 1998, and decreased through 2003; H' increased in 2008 and then remained stable between 2008 and 2011, whereas $1 - \lambda$ greatly increased from 2008 to 2011 (Figure 5b).

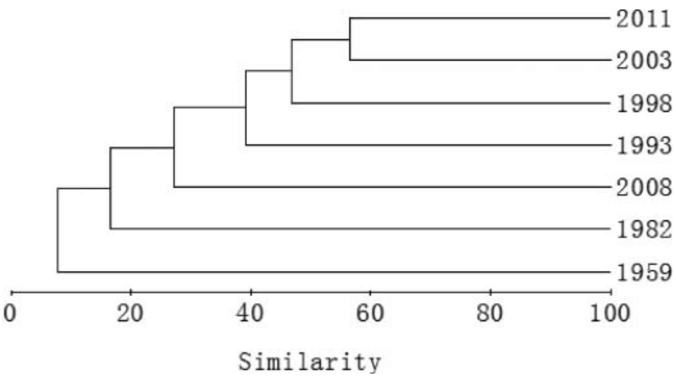

FIGURE 4. Cluster analysis dendrogram based on Bray–Curtis similarity (%) between samples of fish assemblages in the Yellow River estuary from 1959 to 2011.

DISCUSSION

Variations in Community Structure and Diversity

In the Yellow River estuary, no more than 40 fish species were collected during the main spawning season in each study year from 1959 to 2011, with the exception of the 1982 season, during no more than 25 families were collected. According to the survey analysis, the fish species composition changed in the Yellow River estuary. Only a few species were found

TABLE 3. Functional group composition of fish in the Yellow River estuary ecosystem during 1959–2011 (G1 = planktivores; G2 = planktivores/benthivores; G3 = benthivores; G4 = benthivores/piscivores; G5 = omnivores; G6 = mobile piscivores; G7 = elasmobranchs; G8 = roving piscivores).

		Trophic structure							
Year	Variable	G1	G2	G3	G4	G5	G6	G7	G8
1959	Weight (kg/h)	4.28	3.99	1.41	9.15	68.56	331.37	2.04	0.07
	Weight (%)	1.0	1.0	0.3	2.2	16.3	78.7	0.5	0.1
	Species (%; $n = 32$)	18.8	9.4	9.4	18.8	12.5	15.6	12.5	3.1
1982	Weight (kg/h)	117.52	8.38	1.69	4.68	17.82	6.97	0.10	0.24
	Weight (%)	74.7	5.3	1.1	3.0	11.3	4.4	0.1	0.2
	Species (%; $n = 47$)	22.9	14.6	22.9	14.6	10.4	6.3	2.1	6.3
1993	Weight (kg/h)	31.04	0.07	0.32	0.06	0.57	0.10	0.63	0.00
	Weight (%)	94.7	0.2	1.0	0.2	1.7	0.3	1.9	0.0
	Species (%; $n = 29$)	33.3	7.4	22.2	7.4	11.1	14.8	3.7	0.0
1998	Weight (kg/h)	3.03	0.00	0.09	0.07	0.05	0.18	0.01	0.01
	Weight (%)	88.2	0.0	2.7	2.0	1.5	5.3	0.1	0.3
	Species (%; $n = 35$)	39.4	0.0	27.3	9.1	12.1	6.1	3.0	3.0
2003	Weight (kg/h)	4.37	0.00	0.16	0.01	0.32	0.03	0.00	0.05
	Weight (%)	88.6	0.0	3.3	0.1	6.5	0.6	0.0	1.0
	Species (%; $n = 25$)	50.0	0.0	20.8	8.3	8.3	4.2	0.0	8.3
2008	Weight (kg/h)	0.19	0.00	0.02	0.00	0.02	0.01	0.00	0.01
	Weight (%)	75.5	0.0	9.2	0.0	7.0	5.6	0.0	1.4
	Species (%; $n = 19$)	58.8	0.0	17.7	0.0	11.8	5.9	0.0	5.9
2011	Weight (kg/h)	1.58	0.19	0.09	0.05	0.61	0.05	0.01	0.25
	Weight (%)	56.1	6.7	3.0	1.9	21.7	1.8	0.1	8.8
	Species (%; $n = 25$)	36.0	4.0	20.0	8.0	8.0	12.0	4.0	8.0

consistently in every sampling year, and most of these were pelagic species, including the Japanese Anchovy, Scaly Hairfin Anchovy, Smallhead Hairtail, Dotted Gizzard Shad, Madura Anchovy, and White Gunnel; two benthopelagic species, the Silver Pomfret and Small Yellow Croaker, were also collected in each study year. Values of J', H', and $1 - \lambda$ gradually increased from 1959 to 2011, but Margalef's R fluctuated, increasing from 1959 to 1993, decreasing through 2003, and increasing again in 2008. The high diversity of fish might be related to high primary production in this estuary, which forms the major spawning grounds and habitat for many commercial species in the Bohai Sea and Yellow Sea. In 1959, the dominant species in the fish catch were the Largehead Hairtail and Small Yellow Croaker, accounting for 93.9% of the total catch and exhibiting CPUEs greater than 60 kg/h. In recent years, pelagic species were the dominant species in the fish catch, but their CPUEs were less than 1 kg/h. Similar results were found during a study of the fishery resource structure and dynamics of the dominant species composition in Laizhou Bay (Jin and Deng 2000) and during a study of the ichthyoplankton composition in Laizhou Bay (Wang 2009). The larval abundance was primarily a measure of the spawning biomass and reproductive effort of the adult stock in each year, and long-term trends in larval abundance reflected trends in adult biomass. Several studies have shown that larval abundance is a good indicator of adult biomass (Moser et al. 2000, 2001).

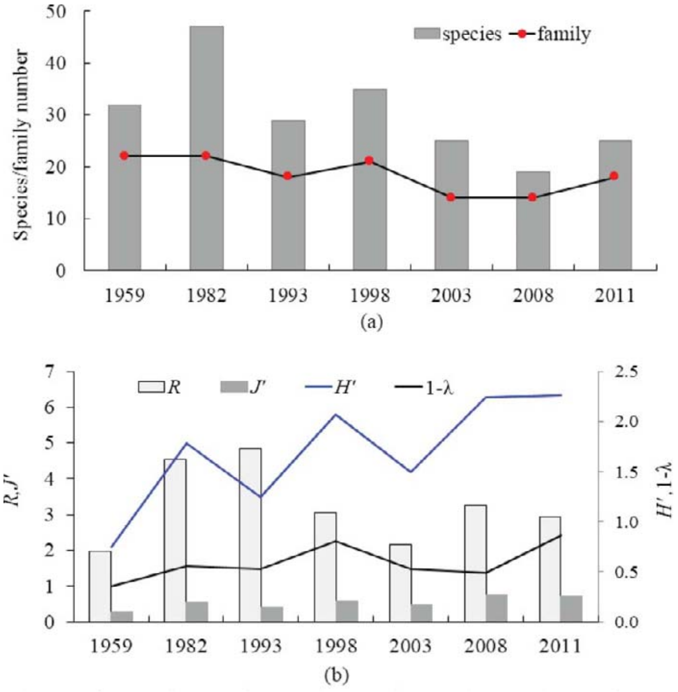

FIGURE 5. Changes in **(a)** the number of fish species or families and **(b)** fish diversity in the Yellow River estuary from 1959 to 2011 (indices: R = Margalef's richness index; J' = Pielou's evenness index; H' = Shannon–Weaver diversity index; $1 - \lambda$ = Lande's diversity index).

In the present study, Engraulidae was the common dominant family in the fish catch during the study years (except 1959), particularly from 1982 to 2003. The engraulid catch accounted for more than 50% of the total catch. Two families, Trichiuridae (78.4%) and Sciaenidae (16.3%), were predominant components of the fish catch during 1959. In 2008, Stromateidae (29.8%), Engraulidae (18.8%), and Polynemidae (14.5%) were the dominant families in the total catch. Engraulidae (30.9%), Percidae (21.8%), and Sciaenidae (16.9%) were the dominant families in the total catch during 2011. Correspondingly, the MTL of the fish catch decreased from 1959 to 1998, increased slightly in 2003, maintained a stable level from 2003 to 2008, and then increased in 2011. Fish species in the catch were mainly distributed at trophic levels 3.5–4.5 from 1959 to 1993; thereafter, the MTL of the fish catch was mainly distributed from 3.0 to 4.0. Over the study period, the functional groups G6 and G5 were replaced by G1 and G2. In addition, distinct differences were found in the fish catch from 1959 to 2011 based on Bray–Curtis similarity analysis. The fish community structure in the Yellow River estuary ecosystem became simpler; regime shifts of the fish community increased, which would be helpful in restoring pelagic fish resources with high restoration potential (Jin and Deng 2000). Thus, with the increase in human activities and climate change, the fishery resource structure and the dominant species composition in the Yellow River estuary changed, the average fish catch declined, and small-sized, low-trophic-level pelagic fishes became the dominant species in the catch.

Threats to Fish Assemblage Structure

Changes in the fish assemblage structure within the Yellow River estuary are mainly due to human-induced disturbance and climate change. The anthropogenic activities include overfishing, dam construction, land reclamation, and eutrophication. Climate change includes alterations in SST, rainfall, and other related factors. Overfishing, dam construction, and climate change are among the most serious problems contributing to the variations in fish assemblage structure and fisheries.

Overfishing.—Overfishing is considered the key reason for the decline of fish stock abundance in the Yellow River estuary (Jin and Tang 1998; Jin and Deng 2000). For example, the biomass of the fishery resources declined continuously from 423.6 kg·haul^{-1}·h^{-1} in 1959 to 164.6 kg·haul^{-1}·h^{-1} in 1982, 37.7 kg·haul^{-1}·h^{-1} in 1993, and less than 8 kg·haul^{-1}·h^{-1} in 1998–2008, largely due to overfishing (Jin et al. 2013). Figure 6D illustrates the decrease in fish abundance with increasing total fishing effort in the Bohai Sea, particularly for the Japanese Anchovy and Scaly Hairfin Anchovy. Although small-sized fishing vessels (hp < 50 kW) dominated the fishing industry in the Yellow River estuary, they were characterized by high fishing intensity (total hp in 2010 was approximately 40 times that in 1959) due to the greater availability of fishing gears. Nonselective fishing gears had serious impacts on juveniles of the fishery-targeted species and greatly destroyed their habitats, thereby causing some migrant species to be extirpated and leading to a sharp decline in the fishery resources (Zhang et al. 2010b). The changes in the Yellow River estuary's fish assemblage structure directly impacted the recruitment and fisheries in the Bohai Sea and Yellow Sea (Jin and Deng 2000).

Overfishing is now widely recognized as one of the most significant anthropogenic activities (Edgar et al. 2005). Overfishing not only has direct impacts on the stock fluctuation of target species at high trophic levels (Hutchings and Baum 2005) but also affects fish communities and ecosystems via cascading ecosystem effects (Pinnegar et al. 2000). Overfishing also results in a decrease in the MTL of catches (Pauly et al. 1998) by altering the extent of top-down regulation of fish assemblage structure (Tegner and Dayton 2000). Overfishing causes changes in the food habits of some dominant species and alters food chains and food webs in marine ecosystem (Pauly et al. 1998; Jin et al. 2010); it also impacts the spatial and temporal distributions of some species. Previous studies have shown that fishing has depleted 50–70% of marine fish populations (Hilborn et al. 2003), and the trophic level in the global fishery catch decreased from 3.3 in the 1950s to 3.1 in 1994. In recent decades, the trophic level has decreased by 0.1 every 10 years (Pauly et al. 1998). Correspondingly, the trophic level in the Bohai Sea decreased from 4.1 in 1959 to 3.4 in 1998–1999, and this decrease was higher than that observed worldwide (Zhang and Tang 2004). Because fisheries tend to target large, commercially important species, the removal of large, top-level predators can effectively reduce the amount of predation risk for smaller individuals, leading to an increased abundance of nontarget species. Nontarget species, particularly those with earlier maturity and smaller size, are generally more resistant to fishing pressure (Piet et al. 2009). Consequently, fluctuations in these small pelagic fishes change the biological structure of the community or ecosystem via the "wasp-waist" middle-trophic-level mechanism (Cury et al. 2000). The Japanese Anchovy, which is the key species of the food web and the main commercial species in the Yellow River estuary, has greatly declined since 1993, thus accelerating the changes in the estuarine food web and trophic levels (Jin and Deng 2000). These changes led to the succession in fisheries from long-lived, high-trophic-level, piscivorous fish to short-lived, low-trophic-level, planktivorous pelagic fish (Jin and Tang 1998; Pauly et al. 1998; Jin and Deng 2000; Savenkoff et al. 2007; Jin et al. 2010), and fisheries decreased to the point that some stocks in the ecosystem collapsed (Jackson et al. 2001).

In addition, studies have shown that the decline in Small Yellow Croaker stock abundance due to overfishing has caused the average body length of this species in the Yellow Sea to greatly decrease from 20 cm in the 1960s to 10 cm in the 2000s; a simpler age structure found in the Small Yellow Croaker population was also attributed to overfishing (Johannessen et al. 2001; Zhang et al. 2010a; Shan et al. 2011). Maturation patterns were seriously affected by continuous high fishing intensity, possibly leading to reversible changes in the age and length at 50% maturity (Ernande et al. 2004; Li 2011). The fishing-induced

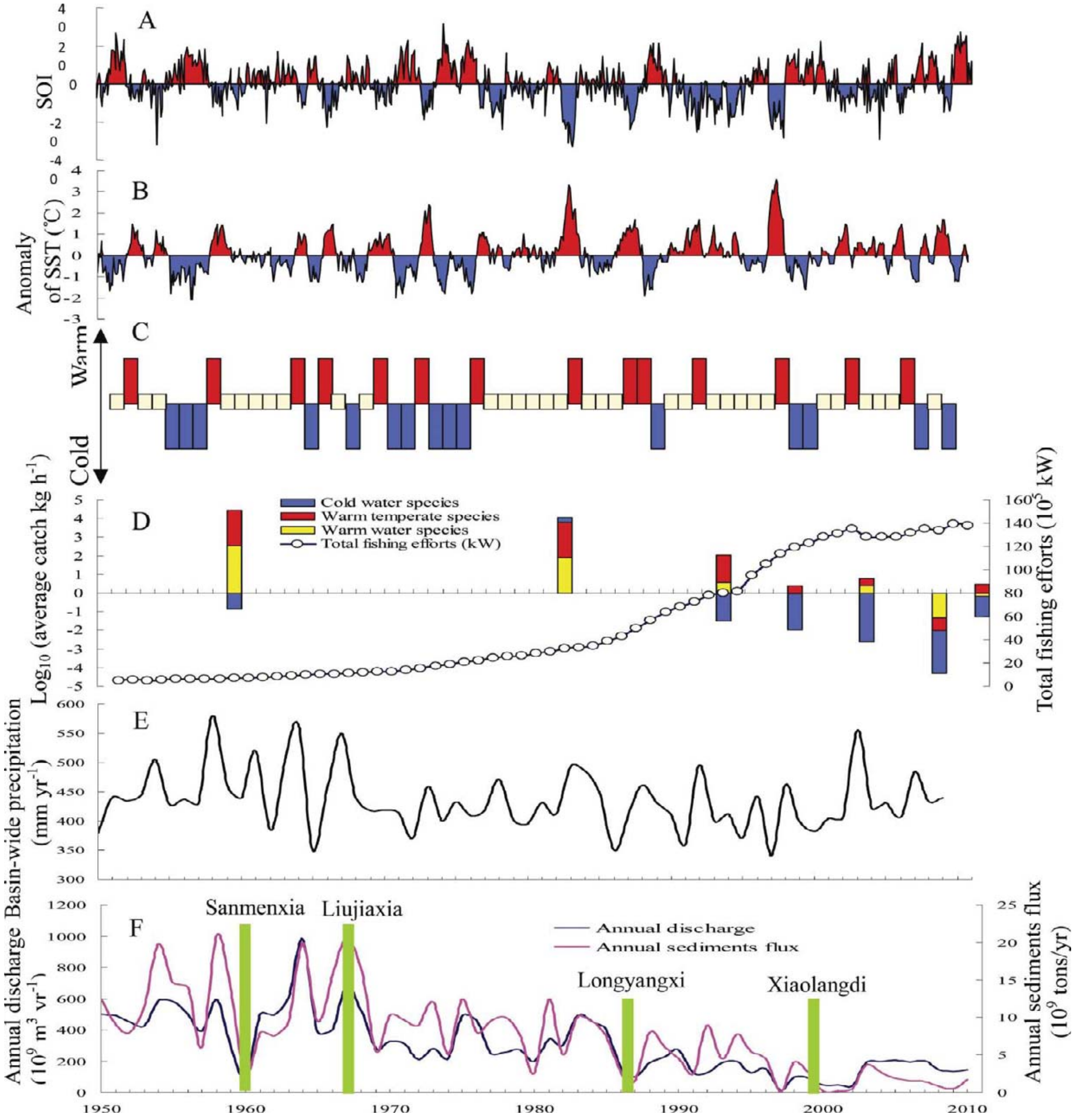

FIGURE 6. Correlation of **(D)** fish catch (kg/h) in the Yellow River estuary and **(A)** the Southern Oscillation Index (SOI), **(B)** monthly sea surface temperature (SST) anomalies, **(C)** warm and cold SST phases, **(E)** annual basinwide precipitation (mm/year) in the Yellow River drainage basin, and **(F)** annual water discharge (pink line; 10^9 m^3/year) and annual sediment flux (deep-blue line;10^9 metric tons/year) at Lijin during 1950–2011 (green bars show the years of construction for main dams on the Yellow River).

change in the ecosystem by selectively harvesting immature fish or only mature fish in populations has been characterized (Engelhard et al. 2004). Overfishing can lead to a decrease in stock abundance (Chen and Mello 1999); can affect population parameters, including growth rate, size (Hutchings and Baum 2005; de Roos et al. 2006), reproductive age, and age structure (Rochet 1998; Bianchi et al. 2000); and can cause variations in genetic structure (de Roos et al. 2006). This signals significant changes in the structure and function of the ecosystem.

Climate change.—There is considerable evidence that pelagic species naturally dominate global ecosystems and that the large fluctuations in small pelagic species are driven by climate change rather than fishing (Rijnsdorp et al. 2009; Alheit and Bakun 2010). In recent years, the fishery catch from the Bohai Sea was approximately 1.3 million metric tons, including 0.5 million metric tons from the Yellow River estuary. The dominant species in the catch were mainly warmwater and warm-temperate pelagic species, and the fishery abundance increased during warm periods or 1–2 years after a warm period (Figure 6A–E). Recent studies have revealed that regime shifts, decadal-scale variability in atmospheric and oceanic environments, or a combination of these strongly influence the dynamics of fish stocks and ecosystems (Stige et al. 2006; Perry et al. 2010), particularly for pelagic species. In addition, long-term variability in the abundance of larval fish is strongly affected by climate; there was an 85% increase in larval abundance from the cold period to the warm period, and 71% had a significant relationship with environmental signals (Tian et al. 2004). Growing evidence suggests that the dynamics of the demersal fish community are linked with climate variability (Attrill and Power 2002; Tian et al. 2004). In the present study, an understanding of the link between fishery species and climate change includes (1) changes in distribution due to the changes in SST (Perry et al. 2010; Dulvy et al. 2008; Brander 2010); (2) changes in the trophic structure via changes in primary and secondary production (Salen-Picard et al. 2002); (3) changes in stock abundance, such as recruitment, growth, survival, reproduction, and migration behavior (Reist et al. 2006; Pörtner et al. 2007; Li 2011); and (4) changes in the diversity of the fish community (Butchart et al. 2010; Powers et al. 2010). Previous studies have shown that the spawning, recruitment, and distribution of fish were closely related to climatic indices, such as the North Atlantic Oscillation and ENSO (Alheit et al. 2005; Rojas-Mendez et al. 2008). The growth of zooplankton and phytoplankton also changed with the increase in SST and further affected the predator–prey relationship. For example, changes in SST caused a mismatch between the fish spawning period and the algal bloom in spring, leading to starvation of the larvae and juveniles and further impacting the fish community structure, distribution, and abundance (Fan et al. 2001). Such changes in turn lead to changes in the marine ecosystem (Reid et al. 2001; Beaugrand et al. 2004). For example, distribution of the Skipjack Tuna *Katsuwonus pelamis* increased with the expansion of the ENSO warm pool, and the Skipjack Tuna fishing grounds extended to 6,000 km along the equator (Lehodey et al. 1997); furthermore, distribution areas of the Peruvian Anchovy *Engraulis ringens* extended to southern Peru, and their abundance decreased during the ENSO period. The abundance of other pelagic species (e.g., Pacific Sardine *Sardinops sagax*, Chilean Jack Mackerel *Trachurus murphyi* [also known as Inca Scad], Chub Mackerel *Scomber japonicus*, and Longnose Anchovy *Anchoa nasus*) increased during and after the ENSO period, and the Shannon–Weaver diversity index increased from 0.87 to 1.23–1.70 during the ENSO period in 1997–1998 (Ñiquen and Bouchon 2004). The dynamics of Pacific Herring *Clupea pallasii* corresponded to the 36-year wet–dry period and 36 years of atmospheric circulation (Tang 1981).

Other threats.—The recent trend in Asia has been toward more and larger dams. Through 2006, a total of 2,752 dams or reservoirs were built in the Yellow River basin; collectively, these reservoirs hold more than 77,500 million m^3, including 22 mid-size and large reservoirs that hold more than 68,200 million m^3 and thus account for 88% of the total water storage. The Sanmenxia, Liujiaxia, Longyangxia, and Xiaolangdi dams were constructed in 1960, 1968, 1985, and 1999, respectively, causing declines in sediment flux and runoff into the sea (Figure 6F); zero flow was observed in the Yellow River during 1997. The decreases in sediment flux and runoff were directly responsible for coastal erosion in the Yellow River estuary basin; additionally, degradation of ecological service function and the frequency of pollution accidents and harmful algal blooms have increased. Consequently, the marine ecological environment has been destroyed, which directly threatens biological reproduction in and ecological security of the inshore ecosystem (Tang et al. 2010). With the decrease in runoff from the Yellow River, the diversity, abundance, and recruitment of fishery species in the Bohai Sea decreased, particularly for the fleshy prawn *Fenneropenaeus chinensis.* Changes in sediment flux into the sea caused alterations in the Yellow River estuary coastline, thereby changing the circulation fields in the coastal waters. These changes further impacted the distribution of fleshy prawn eggs and juveniles, eventually leading to the loss of fleshy prawn eggs and juvenile habitat in Laizhou Bay (Huang and Su 2002). In addition, some studies have reported that the changes in Yellow River runoff were related to climate changes in the basin. Precipitation accounted for 40–50% of the changes in Yellow River runoff (Wang et al. 2006). Based on an analysis of runoff, water consumption, and precipitation at the main hydrological stations from 1950 to 2005, Wang et al. (2006) reported that the global ENSO occurrence directly affected basinwide precipitation and accounted for 51% of the changes in Yellow River runoff, whereas dam construction accounted for 49%.

Land reclamation, eutrophication, pollution, and aquaculture in the coastal waters are also serious problems in the Yellow River estuary, as they contribute to the decline in fish biodiversity and the changes in fish assemblage structure. The effects of these anthropogenic factors on fish assemblage structure in the Yellow River estuary have been discussed in detail by other authors (Zhao et al. 2000; Cui et al. 2005; Li 2011). Land reclamation, eutrophication, pollution, and aquaculture in coastal waters have destroyed the spawning grounds and habitats of many species and have affected fish migration by causing changes in hydrological characteristics, leading to declines in fishery resources.

Conclusions

Fish assemblage structure and fish diversity in the Yellow River estuary ecosystem have changed, and the estuary is at risk for being significantly compromised by overfishing, climate change, dam construction, and pollution. These problems are causing the decline of traditional fishing industries and a reduction in biodiversity in the Yellow River estuary. Currently, certain traditional commercially targeted fishes (e.g., Largehead Hairtail, Red Seabream, and Pacific Herring) are locally extinct, and the dominant species have rapidly shifted from highly valued, high-trophic-level, large-sized demersal species with complicated age structures to low-value, low-trophic-level, small-sized pelagic species with simple age structures, resulting in major disruption of the ecological cycle and hindering the restoration of fishery resources.

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