DYNAMIC CHARACTERISTICS OF COMMUNITY STRUCTURE AND SEASONAL VARIATION OF FISHERY SPECIES IN THE BOHAI SEA, CHINA

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Abstract. The structural patterns and the seasonal dynamics of fishery species were studied in the Bohai Sea, based on fishery-independent data surveyed in each season sampling stations. A total of 88 fishery species belonging to 64 families were recorded, in detail 43 fishes, 29 crustaceans, 12 molluscas, three echinoderms and one species of scyphozoan. Among them, 21 species commonly found throughout the study period defined as 'common' species, and eight species those were the highest contributors defined as 'dominant' species (based on SIMPER analysis, their cumulative contribution was more than 70%). Maximum abundance was recorded in the summer season while species number was higher in both summer and autumn season. Among the community parameters, species richness (3.79), diversity (2.31) and Simpson indices (0.88) peaked in the autumn season whereas species evenness (0.95) was in the winter. However, species diversity, evenness, and Simpson indices were lower in the summer season (0.57, 0.18 and 0.18, respectively) while species richness was in the winter (1.65). Multivariate PCoA analysis revealed that there was a significant seasonal variation in fisheries assemblages. Furthermore, ANOSIM (Global $R = 0.467$, $P = 0.01$) indicated a distinct community structure of fishery species between the four seasons. Thus, this result suggests that fisheries assemblages might be influenced by the seasonal dynamics of the ecological condition of the Bohai Sea.
Keywords: *fisheries assemblages, multivariate analyses, community parameters, seasonal patterns, trawl survey data*

Introduction

The Bohai Sea, a semi-enclosed inland sea is a unique waterbody that houses rich marine and coastal biological resources (i.e., fishes/shellfishes; oil, gas, and minerals; estuaries; tidal flats; seagrass beds) as well as a great potentiality for mariculture and tourism purpose in the northeastern China (Zhang et al., 2002; Song and Duan, 2018). However, the rapid human settlement and industrial development that was triggered from 1985 along the coast of Bohai Sea accelerated the degradation in estuarine and marine ecosystems by altering hydro-pedological properties (i.e., water and sediments qualities) over the decades (Liu et al., 2011; Gao et al., 2014; Li et al., 2016). Besides, the changing climate variabilities such as temperature (*T*), salinity (*S*), and biogenic elements altered the Bohai Sea ecosystems which significantly influenced the living biotic communities (Lin et al., 2001; Yu et al., 2009). The variations of species in the communities are closely interrelated with the ecological conditions of water masses. Over the recent decades, anthropogenic activities mainly linked to urbanization and industrialization have a notable effect on the species diversity of the primary producers and benthos communities which may have triggered off the declining trend of fishery populations in the Bohai Sea (Hu et al., 2011; Liu et al., 2011).

Several studies have been focused on the characteristics of fish and fishery dynamics of the Bohai Sea (Chen et al., 1997; Tang et al., 2003; Jin, 2004; Shan et al., 2012, 2016; Zhang et al., 2012). Investigations have been reported that fishery stock status in the Bohai Sea experienced declining trends (Liu et al., 1990; Zhang et al., 2006; Zhou et al., 2013). Moreover, the Bohai Sea has been considered one of the most exploited fishing ground in the world (Wu et al., 2017; Liu et al., 2017). As a result, species abundance, diversity, and trophic structure had significantly shrunk in this ecosystem (Deng and Jin, 2001; Jin, 2004; Zhang and Tang, 2004; Shan et al., 2012). Spatio-temporal shifts of dominant species from large-size of high economic value to short-lived, low-trophic-level, low economic value and changes of ecosystem structure and functioning on the decadal-scale have been documented (Shan et al., 2013, 2016; Rahman et al., 2019).

The present study accounts the Bohai Sea as a major fishery center in China in view, and evaluated a one-year fishery-independent data (i.e., a pair of trawlers) to analyze the community patterns and dynamics of the fishery species. The specific aims of the research were (a) to document the taxonomic composition and species distribution patterns of fishery species, and (b) to illustrate the community patterns and the seasonal dynamics of fishery species during the study period.

Materials and methods

Study area

The Bohai Sea (37°07`~41°N and 117°35`~121°10`E) is a semi-enclosed marginal sea of the northwestern Pacific Ocean on the northern coast of China. It extends for about 450 km from north to south and about 350 km from east to west, where the Bohai Strait is used as a junction to the Yellow Sea between Shandong and Liaodong Peninsulas (*Fig. 1*). It has an area of 77,000 km^2, which includes Bohai, Laizhou, and Liaodong Bays. The water depth varies at 10-20 m in the continental shelf where maximal water depth of 70 m is recorded in the northern part of Bohai Strait. The hydrographic conditions have greatly influenced by many factors such as river discharges, wind–tide–thermohaline circulation, stratification during summer, and vertical and horizontal mixing of nutrients in winter that support higher primary productivity (Ning et al., 2010).

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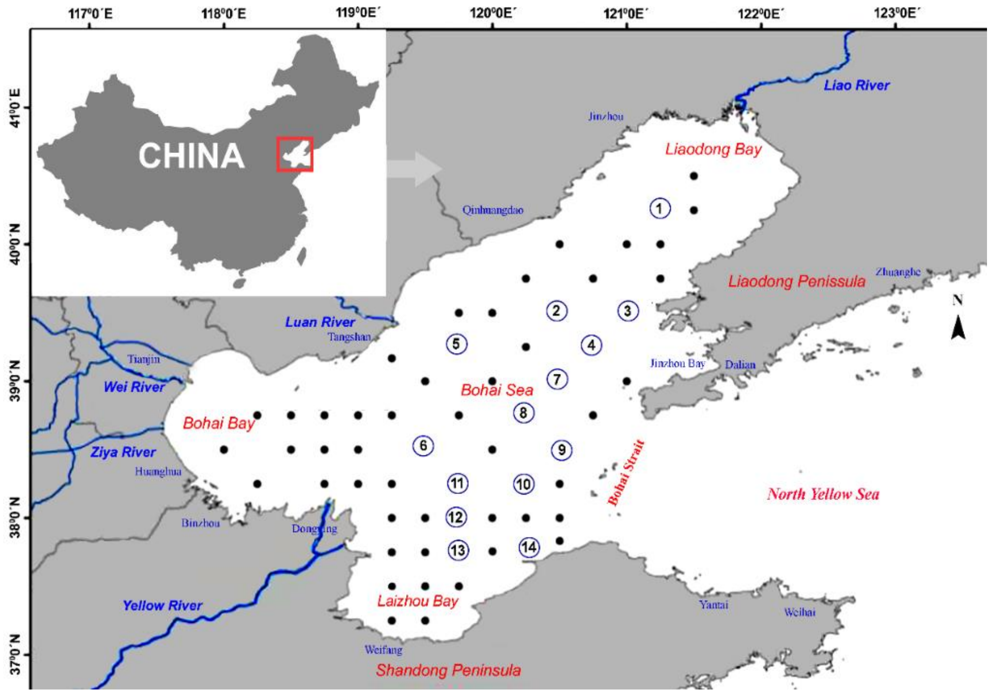

Figure 1. *Geographical locations of sampling points in the Bohai Sea, China*

Data source

Data were collected from a pair trawler (i.e., the capability was 200 horsepower; the distance between wings was 22.6 m, headline height was between 5 m and 6 m, cod mesh size was 2 cm, and circumference was 30.6 m.) survey carried out by the Yellow Sea Fisheries Research Institute. The surveyed sampling stations were designed on a fixed station grid of 0.5°N × 0.5°E. The hauls were lowered for sampling during the daytime, the duration at least 15 minutes to 60 minutes and an average hauling speed of 5.09 km/h. The average sampling depth was 23.18 meters (*Table 1*). All data were then standardized to a one-hour trawl duration for consistency. The survey period divided into four seasons namely as winter (January), spring (May), summer (August), and autumn (November) season. Samples were collected from the fixed 70 sampling stations. Among them, 14 stations were surveyed in each season. We selected these common sampling stations for analysis among the seasons.

Collected fishery specimens at each station were sorted firstly family and order level, then to species level, or the lowest possible taxon level. Subsequently, total abundance/individual abundance and species composition were recorded. The abundance of the species was expressed as the number of individual species catch per haul (ind./haul), and the composition of the species was expressed as a percentage of the total number of species recorded (%).

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Table 1. *Position and characteristics (latitude, longitude, sampling site, aver. depth and aver. haul speed) of the sampling stations during the pair-trawl survey in the Bohai Sea*

Station SL No.	**Net placement**		**Sampling site**	**Average depth (m)**	**Average haul speed (km/h)**
	Latitude	Longitude			
1	40°25′ N	121°25′ E	Liaodong Bay	23.6	5.19
2	39°50′ N	120°50′ E	Liaodong Bay	25.9	5.06
3	39°50′ N	121°00′ E	Liaodong Bay	25.2	4.39
4	39°25′ N	120°75′ E	Liaodong Bay	25.73	4.87
5	39°25′ N	119°75′ E	Central Bohai	25.8	5.24
6	38°50′ N	119°50′ E	Central Bohai	25.83	5.0
7	39°00′ N	120°50′ E	Central Bohai	24.57	5.56
8	38°75′ N	120°25′ E	Central Bohai	25.83	5.13
9	38°50′ N	120°50′ E	Central Bohai	28.43	5.43
10	38°25′ N	120°25′ E	Central Bohai	23.93	4.95
11	38°25′ N	119°75′ E	Laizhou Bay	22.67	4.82
12	38°00′ N	119°75′ E	Laizhou Bay	16.73	5.69
13	37°75′ N	119°75′ E	Laizhou Bay	15.33	5.13
14	37°75′ N	120°25′ E	Laizhou Bay	14.93	4.82

Data analysis

Diversity patterns of fishery species were summarized by frequently used diversity measuring indices such as Shannon-Wiener Index (*H'*) (Shannon & Weaver) (*Eq. 1*), species evenness (*J'*) (Pielou) (*Eq. 2*), species richness (*d*) (Margalef) (*Eq. 3*) and Simpson index (1-λ′) (Simpson) (*Eq. 4*), these four indices were measured using the following formulas:

$$H' = \sum_{i=1}^{S} P_{i(lnP_i)} \quad \text{(Eq.1)}$$

$$J' = H'/lnS \quad \text{(Eq.2)}$$

$$d = (S-1)/lnN \quad \text{(Eq.3)}$$

$$1-\lambda' = 1 - SUM\left(N_i * (N_i - 1)\right)/\left(N * (N-1)\right) \quad \text{(Eq.4)}$$

where, H'= observed diversity index; P_i= proportion of the total count arising from the *i*th species; S= total number of species; and N= the total number of individuals.

Both multivariate and univariate analyses were conducted for summarizing seasonal variation in fishery dynamics and their seasonal patterns of community structure using PRIMER v7.0.13 and IBMSPSS v.22. The patterns of species distribution between the four seasons were analyzed by shade plotting analysis from average standardized species abundance data. The species whose presence was available in all four seasons were defined as ‘common species’ in the community. The contribution of each species to the average Bray-Curtis similarity among the 14 trawls stations was calculated using SIMPER (similarity percentage analysis) program. Based on the SIMPER analysis, those

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species have a cumulative contribution of more than 70% in the total communities were defined as 'dominant species'. Both the dominant and common species identified as an important species in the fishery communities (Zhu and Tang, 2002; Shan et al., 2016). The significant differences of the fisheries community structure among the seasons were tested using ANOSIM (analysis of similarity) (Anderson et al., 2008; Clarke and Gorley, 2015). The seasonal variations in fishery assemblages were analyzed by coordination of the submodule of PCoA (Principal coordinates analysis) of PREMANOVA + of Bray–Curtis similarities from square root transformed species abundance data (Anderson et al., 2008; Clarke and Gorley, 2015).

A simple Pearson correlation matrix was performed to identify an existing correlation among the dominant species of fishery communities using IBMSPSS v.22, and data were log-transformed before analysis.

Results

Taxonomic composition and species distribution

A total of 88 species belonging to 64 families were identified. These fishery samples included 43 fish species belonging to 28 families, 29 crustacean species belonging to 21 families, 12 mollusca species belonging to 11 families, three echinoderm species belonging to three families and one species of scyphozoan. The list of identified fishery species including their seasonal distribution, average abundance, frequency of occurrence was summarized in *Table 2.* Among the species, 21 species were reported common in terms of their presence in all four seasons, and eight species were found to be dominant with their higher contribution in the communities.

Based on the species distribution patterns, 19 species were present in three seasons, 18 species were present in two seasons, and 30 species were distributed only in one season (*Fig. 2*).

In terms of dominance (result from SIMPER analysis >70%), six species belonged to crustaceans (*Alpheus japonicas*, 15.34%; *Oratosquilla oratoria*, 11.57%; *Palaemon gravieri*, 10.57%; *Crangon affinis*, 8.85%; *Acetes chinensis*, 7.53%; *Leptochela gracilis*, 7.19%) and others were one fish species (*Engraulis japonicas*, 6.30%) and one cephalopod species (*Loligo japonica*, 8.51%) (*Table 2* and *Fig. 2*).

In terms of species belonging to family, the maximum number of species were recorded under the family of Gobiidae with seven species (*Amblychaeturichthys hexanema*, *Chaeturichthys stigmatias*, *Cryptocentrus filifer*, *Favonigobius gymnauchen*, *Ctenotrypauchen chinensis*, *Synechogobius hasta*, and *Odontamblyopus rubicundus*), followed by the family of Engraulidae with five species (*Coilia mystus*, *Engraulis japonicas*, *Setipinna taty*, *Thrissa kammalensis,* and *Thrissa mystax*) and the Penaeidae with four species (*Fenneropenaeus chinensis, Marsupenaeus japonicas, Metapenaeopsis dalei* and *Trachypenaeus curvirostris*) (*Table 2*).

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Table 2. *List of fishery species recorded in the Bohai Sea during a one-year cycle including their seasonal distribution, average abundance, frequency of occurrence and dominant species based on SIMPER analysis*

	Family	Species name	Dist.	Winter		Spring		Summer		Autumn	
				N	**%**	***N***	**%**	***N***	**%**	***N***	**%**
Fish	Ammodytidae	*Ammodytes personatus* (Girard, 1856)	---+	-	0	-	100	-	0	-	0
	Apogonidae	*Apogonichthys lineatus* ((Temminck & Schlegel, 1842)	--++	-	0	-	0	+	97.92	-	2.08
	Arcidae	*Scapharca broughtonii (Schrenck, 1867)*	-+--	-	0	-	100	-	0	-	0
	Callionymidae	*Callionymus beniteguri* (Jordan & Snyder, 1900	++++	+	14.63	-	3.84	+	63.85	+	17.68
	Clupeidae	*Konosirus punctatus* ((Temminck & Schlegel, 1846)	--+-	-	0	-	0	+	100	-	0
		Sardinella zunasi (Bleeker, 1854)	--+-	-	0	-	0	+	100	-	0
	Cynoglossidae	*Cynoglossus lighti* (Norman, 1925)	++++	+	20.85	+	24.24	+	18.43	+	36.48
		Cynoglossus semilaevis (Günther, 1873)	+-+-	-	46.67	-	0	-	53.33	-	0
	Engraulidae	*Coilia mystus* ((Linnaeus, 1758)	--++	-	0	-	100	-	0	-	0
		Engraulis japonicus (Temminck & Schlegel, 1846)	-+++	-	0	+	1.32	+++++	93.25	+++	5.43
		Thrissa kammalensis (Bleeker, 1849)	-+--	-	0	+	0	+	0	+	100
		Thrissa mystax (Bloch & Schneider, 1801)	-+++	-	0	-	9.62	-	82.52	-	7.86
		Setipinna taty ((Valenciennes, 1848)	-++-	-	1.61	+	81.92	+++	15.38	++	1.08
	Gobiidae	*Amblychaeturichthys hexanema* ((Bleeker, 1853)	++++	-	0.01	+	0.32	+++++	68.74	++++	30.93
		Chaeturichthys stigmatias (Richardson, 1844)	++++	+	6.91	-	0.18	++	57.36	++	35.55
		Cryptocentrus filifer ((Valenciennes, 1837)	++++	-	4.98	+	56.93	-	12.77	-	25.32
		Ctenotrypauchen chinensis (Steindachner, 1867)	-++-	-	0	+	11.95	+	60.51	+	27.54
		Odontamblyopus rubicundus (Hamilton, 1822)	-+++	-	0	-	10.99	-	80.63	-	8.36
		Favonigobius gymnauchen (Bleeker, 1860)	--+-	-	0	-	0	-	100	-	0
		Synechogobius hasta (Temminck & Schlegel, 1845)	+-++	+	0	-	5.89	-	69.43	-	24.69
	Hexagrammidae	*Hexagrammos otakii* (Jordan & Starks, 1895)	-+++	-	0	+	82.61	-	8.70	-	8.70
	Hemiramphidae	*Hyporhamphus sajori* ((Temminck & Schlegel, 1846)	+---	-	100	-	0	-	0	-	0
	Liparidae	*Liparis tanakae* ((Gilbert & Burke, 1912)	++-+	-	0.06	+++	99.87	-	0	-	0.07
	Lophiidae	*Lophius litulon* ((Jordan, 1902)	-+--	-	0	-	3.86	+	65.27	+	30.87

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				N	**%**	***N***	**%**	***N***	**%**	***N***	**%**
	Monacanthidae	*Navodon septentrionalis* (Günther, 1874)	-+++	-	0	-	6.92	-	25.68	-	66.59
	Mugilidae	*Liza haematocheila* ((Temminck & Schlegel, 1845)	+---	-	100	-	0	-	0	-	0
	Paralichthyidae	*Paralichthys olivaceus* ((Temminck & Schlegel, 1846)	--+-	-	0	-	99.97	-	0	-	0.03
	Pholidae	*Enedrias fangi* (Wang & Wang, 1935)	+++-	-	0.38	+++	97.92	+	1.71	-	0
	Platycephalidae	*Platycephalus indicus* (Linnaeus, 1758)	-+--	-	0	-	2.30	+	56.21	-	41.49
	Pleuronectidae	*Pseudopleuronectes yokohamae* (Günther, 1877)	-+++	-	0	-	0	-	100	-	0
	Rajidae	*Raja porosa* (Günther, 1874)	--++	-	0	-	77.89	-	22.11	-	0
	Salangidae	*Protosalanx chinensis* (Osbeck, 1765)	++++	+	50.13	-	100	+	0	+	0
	Sciaenidae	*Argyrosomus argentatus* (Houttuyn, 1782)	--+-	-	0	-	0	+	100	-	0
		Johnius belangerii (Cuvier, 1830)	-+--	-	0	-	35.48	-	64.52	-	0
		Larimichthys polyactis ((Bleeker, 1877)	--++	-	0	-	0	+	99.51	-	0.49
	Scombridae	*Scomber japonicus* (Houttuyn, 1782)	--+-	-	0	-	0	+	100	-	0
		Scomberomorrus niphonius (Cuvier, 1832)	--+-	-	0	-	0	+	100	-	0
	Sebastidae	*Sebastes schlegeli* (Hilgendorf, 1880)	++++	-	0.67	+	6.16	+	92.78	-	0.39
	Stromateidae	*Pampus argenteus* (Euphrasen, 1788)	--++	-	0	-	100	-	0	-	0
	Syngnathidae	*Syngnathus acus* (Linnaeus, 1758)	-+++	-	65.32	-	0	-	5.99	-	28.69
	Tetraodontidae	*Takifugu vermicularis* (Temminck & Schlegel, 1850)	---+	-	0	-	0	-	90	-	10
	Trichiuridae	*Eupleurogrammus muticus* (Gray, 1831)	-+--	-	0	-	13.90	+	56.95	+	29.15
	Zoarcidae	*Zoarces elongates* (Kner, 1868)	-+++	-	0	-	100	-	0	-	0
Crustacean	Alpheidae	*Alpheus distinguendus* (de Man, 1909)	--++	-	0	-	0	+	6.16	+	93.84
		Alpheus heterocarpus (Yu, 1935)	++--	-	7.99	+	92.01	-	0	-	0
		Alpheus japonicus (Miers, 1879)	++++	+++	32.62	+	3.89	++	16.83	+++	46.65
	Cancridae	*Cancer gibbosulus* (De Haan, 1833)	-++-	-	0	+	75.51	-	24.49	-	0
	Crangonidae	***Crangon affinis*** (De Haan, 1849)	++++	+	6.04	++++	85.18	+	0.36	+	8.43
	Dorippidae	*Dorippe japonica* (von Seibold, 1824)	+++-	-	0.62	-	2.13	+	97.25	-	0
	Euryplacidae	*Eucrate crenata* (De Haan, 1835)	--++	-	0	-	0	+	99.11	-	0.89
	Euphausiidae	*Euphausia pacifica* (Hansen, 1911)	-+++	-	0	-	0	-	0	-	0

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				N	**%**	***N***	**%**	***N***	**%**	***N***	**%**
	Goneplacidae	*Carcinoplax vestita* (De Haan, 1835)	++++	+	42.07	+	12.38	+	31.32	+	14.22
	Hemiramphidae	*Hyporhamphus limbatus* (Valenciennes, 1847)	+---	-	100	-	0	-	0	-	0
	Hippolytidae	*Latreutes anoplonyx* (Kemp, 1914)	++--	+	71.79	+	28.21	-	0	-	0
		Latreutes planirostris (De Haan, 1844)	+-++	-	0.42	-	0	+	92.29	+	7.28
	Paguridae	*Paguridae* (Latreille, 1802)	-+-+	-	0	+	21.23	+	5.89	-	26.84
	Leucosiidae	*Arcania heptacantha* (De Man, 1907)	--+-	-	0	-	0	-	100	-	0
	Palaemonidae	***Palaemon gravieri*** ((Yu, 1930)	++++	++	46.06	+	0	+	62.12	+	37.88
	Pasiphaeidae	***Leptochela gracilis*** (Stimpson, 1860)	-+++	-	0	+	13.10	+	0.35	++++	86.55
	Portunidae	*Charybdis bimaculata* (Miers, 1886)	++++	-	1.32	-	10.52	+	23.85	+	64.32
		Charybdis japonica (A. Milne-Edwards, 1861)	++++	-	0.40	-	4.62	+	94.51	-	0.46
		Portunus trituberculatus (Miers, 1876)	-+++	-	0	-	4.23	+	22.07	+	23.57
	Penaeidae	*Fenneropenaeus chinensis* (Osbeck, 1765)	--+-	-	0	-	0	+	100	-	0
		Marsupenaeus japonicus (Spence Bate, 1888)	--+-	-	0	-	0	-	100	-	0
		Metapenaeopsis dalei ((Rathbun, 1902)	-+++	-	0	-	9.27	-	0	+	90.73
		Trachypenaeus curvirostris (Balss, 1933)	-++-	-	0	-	0	+	0	+	100
	Pinnotheridae	*Pinnotheridae* (De Haan, 1833)	---+	-	0	-	10.43	-	89.57	+	0
	Macrophthalmidae	*Tritodynamia rathbunae* (Shen, 1932)	--++	-	0	-	0.75	+	7.55	-	91.70
	Matutidae	*Matuta planipes* (Fabricius, 1798)	--+-	-	0	-	0	+	100	-	0
	Sergestidae	***Acetes chinensis*** (Hansen, 199)	++++	+++	62.64	+	7.28	+	15.73	+	14.35
	Squillidae	***Oratosquilla oratoria*** (De Haan, 1844)	++++	-	0.03	+++	60.08	+++++	39.92	++	0
	Upogebiidae	*Austinogebia edulis* (Ngoc-Ho & Chan, 1992)	----	-	0	-	0.54	-	0.54	+	98.92
Mollusca	Hiatellidae	*Panopea abrupta* ((Conrad, 1849) †	-+--	-	0	-	21.69	-	42.15	-	36.16
	Loliginidae	***Loligo japonica*** (Hoyle, 1885)	++++	-	0.17	+	6.40	++++	76.82	++	16.61
	Muricidae	*Rapana venosa* ((Valenciennes, 1846)	-+--	-	0	+	0	-	100	-	0
	Mytilidae	*Mytilus edulis* (Linnaeus, 1758)	+-+-	-	0	-	0	-	100	-	0
	Nassariidae	*Nassariidae* (Iredale, 1916 (1835))	--+-	-	0	-	100	-	0	-	0
	Naticidae	*Glossaulax didyma* ((Röding, 1798)	++++	-	5.74	+	88.52	-	4.92	-	0.82

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				N	**%**	***N***	**%**	***N***	**%**	***N***	**%**
	Nautilidae	*Nautiloidea* sp.	-+--	-	0	-	0	-	50	-	50
	Octopodidae	*Octopus ocellatus* (Gray, 1849)	++++	-	0.81	+	45.61	+	34.20	+	15.20
		Octopus variablilis ((Sasaki, 1929)	++++	-	4.99	-	0	-	100	-	0
	Philinidae	*Philine kinglipini* (Tchang, 1934)	-+-+	-	0	++++	100	-	0	-	0
	Pinnidae	*Pinna rudis* (Linnaeus, 1758)	--+-	-	0	-	0	-	0	-	100
	Sepiolidae	*Sepiola birostrata* (Sasaki, 1918)	++++	-	0	+	0	+	0	-	0
Echinod.	Asteriidae	*Asierias rollestoni* (Bell, 1881)	-+++	-	0	+	44.06	-	11.59	+	44.35
	Luidiidae	*Luidia yesoensis* (Goto, 1914)	++-+	+	18.25	+	68.45	-	0	+	13.30
	Strongylocentrotidae	*Hemicentrotus pulcherrimus* (A. Agassiz, 1864)	-+--	+	25.37	+	6.06	-	0.38	+	68.19
	Scyphozoa (Class)	*Scyphozoa* sp.	++++	+	98	-	0	-	2	-	0

Text bold, dominant species; Dist., distribution: +, present; -, absent; *N*, average abundance: > 500,"+++++", > 200,"++++", > 100,"+++", > 50,"++", > 1,"+","-"; %, frequency of occurrence

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According to the frequency of occurrence of the dominant species, *Acetes chinensis*, *Palaemon gravieri*, and *Alpheus japonicas* were accounting for 62.64%, 46.06%, and 32.62%, respectively in the winter season (January) while *Crangon affinis* and *Oratosquilla oratoria* were accounting for 85.18% and 60.08%, respectively in the spring season (May). In the summer season (August) *Engraulis japonicus*, *Loligo japonica*, *Palaemon gravieri*, and *Oratosquilla oratoria* were accounting for 93.25%, 76.82%, 62.12%, and 39.92%, respectively whereas *Alpheus japonicas*, *Leptochela gracilis* and *Palaemon gravieri* were accounting for 46.65%, 86.55%, 37.88%, respectively in the autumn season (November) (*Table 2* and *Fig. 2*).

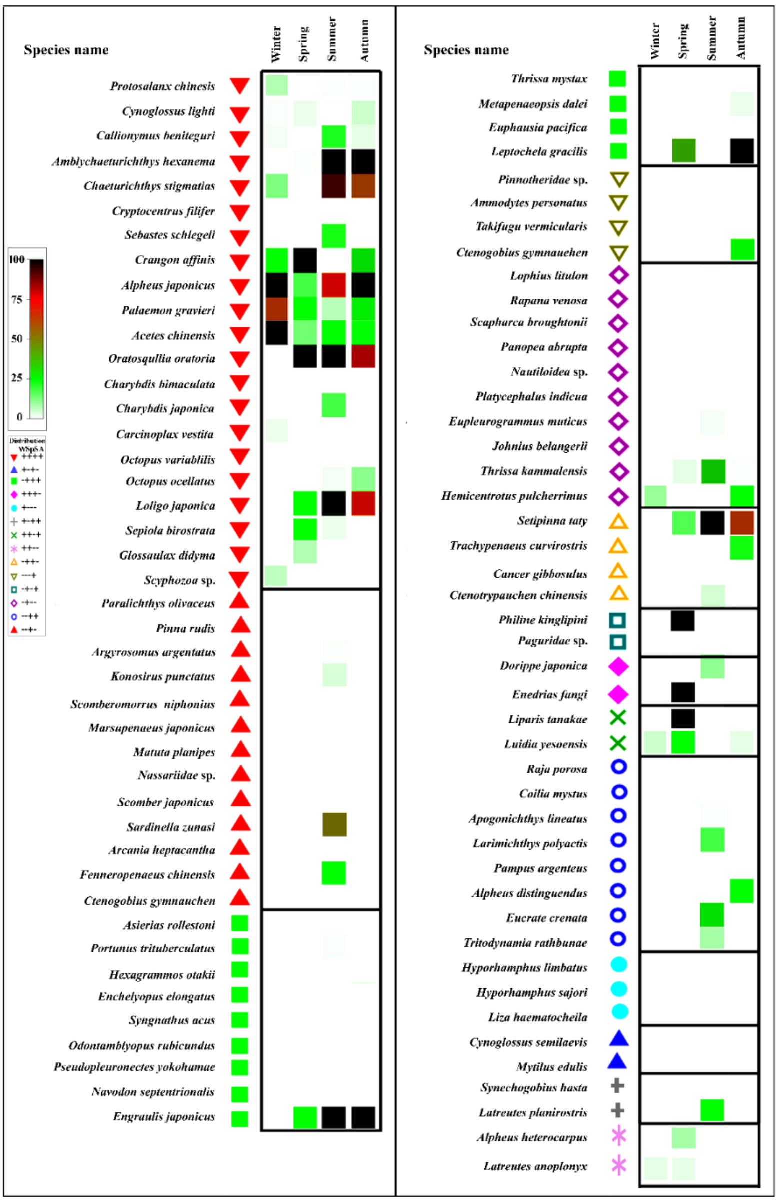

Figure 2. *Shade plot showing the seasonal distribution pattern of fishery species in terms of their relative abundance during the study period in the Bohai Sea*

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Seasonal variation in fishery dynamics

In terms of abundance of dominant species per haul, the individual abundance found to be higher in the summer and lower in the winter (*Fig. 3a*). As to relative abundance, three species of crustaceans were predominant in the winter (*Alpheus japonicas*, *Acetes chinensis* and *Palaemon gravieri*); two species in the spring (*Crangos affinis* and *Oratosquilla oratoria*); two species in the summer (*Engraulis japonicus* and *Oratosquilla oratoria*); and two species in the autumn season (*Leptochela gracilis* and *Alpheus japonicus*) (*Fig. 3b*).

Based on species occurrence, the maximum species occurred in summer and autumn, whereas the minimum was in winter (*Fig. 4a*). For example, of these 88 species, 24 were occurred in summer and autumn, while only seven species were in winter. In terms of total abundance, the highest abundance recorded in summer, while the lowest was in winter (*Fig. 4b*).

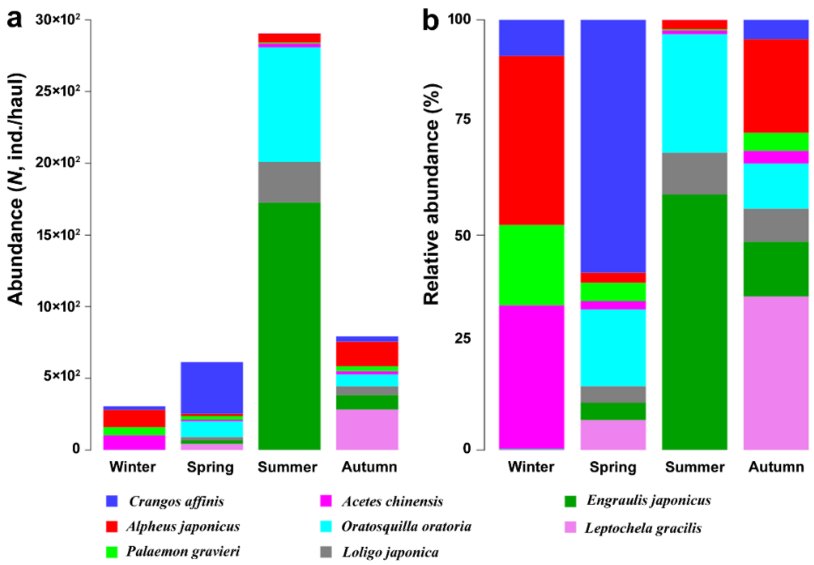

Figure 3. *Variation in abundance and relative abundance of dominant species of fishery species during the study period in the Bohai Sea*

The analysis of similarity (ANOSIM) revealed that there was a significant difference in fishery community structure between the four seasons (Global, R = 0.467, $P < 0.001$). Based on SIMPER analysis, seven typical species (*Crangon affinis, Enedrias fangi, Oratosquilla oratoria, Acetes chinensis, Alpheus japonicas, Liparis tanakae* and *Philine kinglipini*) driven 93.34% average dissimilarities between winter and spring seasons. Similarly, six species (*Engraulis japonicas, Oratosquilla oratoria, Loligo japonica, Alpheus japonicas, Acetes chinensis* and *Chaeturichthys stigmatias*) in winter and spring seasons (97.33%); eight species (*Leptochela gracilis, Alpheus japonicas, Acetes chinensis, Amblychaeturichthys hexanema, Engraulis japonicas, Setipinna taty, Palaemon gravieri,* and *Crangon affinis*) in winter and autumn seasons (90.37%); seven species (*Engraulis japonicas, Oratosquilla oratoria, Loligo japonica, Crangon affinis, Amblychaeturichthys hexanema, Setipinna taty* and *Enedrias fangi*) in spring and summer seasons (95.07); nine species (*Leptochela gracilis, Crangon affinis,*

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Enedrias fangi, Amblychaeturichthys hexanema, Oratosquilla oratoria, Liparis tanakae, Philine kinglipini, Alpheus japonicas and *Engraulis japonicus*) in spring and autumn seasons (89.81%); and six species (*Engraulis japonicas, Oratosquilla oratoria, Loligo japonica, Amblychaeturichthys hexanema, Leptochela gracilis,* and *Setipinna taty*) in summer and autumn seasons (92.29%) (*Table 3*).

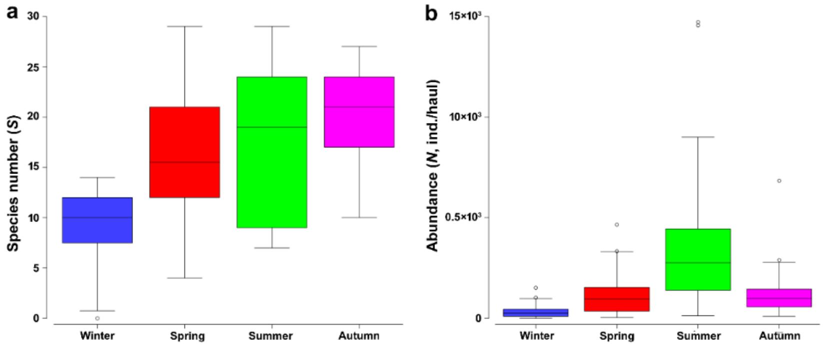

Figure 4. *Seasonal variation in species number (a) and total abundance (b) in the fishery species during the study period in the Bohai Sea*

Seasonal variation in diversity pattern of fishery species

Among the community parameters, the species richness showed increasing trend from winter to autumn season, with a higher value in the autumn and lower in winter while species evenness showed opposite that decreased from winter to summer, then again increased in autumn season with a value higher in winter and lower in summer season (*Fig. 5a,b*). The species diversity (H') and Simpson index (1-λ′) showed similar seasonal patterns and both indices values were higher in autumn and lower in the summer season (*Fig. 5c,d*).

In terms of fishery diversity status, there was a clear temporal variation revealed in the Bohai Sea during the study period (*Fig. 5*). For example, the highest value of species richness (3.79) was found in the autumn season whereas it was the lowest (1.65) in the winter with an average of 2.80±0.59. The species evenness was found to be maximum (0.95) in the winter season and minimum (0.18) in the summer season with an average of 0.63±0.17. The maximum species diversity index was (2.31) recorded in autumn season and minimum (0.57) was in summer season with an average of 1.82±0.44 while Simpson index was found to be similar with diversity that was the highest (0.88) in autumn season and the lowest (0.18) in summer season with an average of 0.73±0.18 (*Fig. 5*).

Patterns of community structural of fishery species

Principal analysis of coordinates (PCoA) summarized the seasonal structural variations in the fishery species. The first canonical axis (PCoA1) separated the samples in winter and spring (on the left) from those in summer and autumn (on the right), while the second canonical axis (PCoA2) discriminated the samples in winter and summer (upper) from those at the others two seasons spring and autumn (lower) (*Fig. 6a*).

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Table 3. *Results of the one-way analysis of similarity (ANOSIM) showing the significant differences and SIMPER results of the typical species driven the seasonal variation in the fishery species during the study period in the Bohai Sea*

Global	ANOSIM		Dissimilarity index from SIMPER		Cont. (%)
R=0.467, P=0.001	R	P	Ave. Diss. (%)	Typical species	
Winter vs Spring	0.531	0.1	93.34	*Crangon affinis*	17.28
				Enedrias fangi	10.02
				Oratosquilla oratoria	9.95
				Acetes chinensis	9.57
				Alpheus japonicas	8.98
				Liparis tanakae	8.57
				Philine kinglipini	6.07
Winter vs Summer	0.593	0.1	97.33	*Engraulis japonicas*	27.82
				Oratosquilla oratoria	18.46
				Loligo japonica	12.25
				Alpheus japonicas	5.17
				Acetes chinensis	5.09
				Chaeturichthys stigmatias	5.04
Winter vs Autumn	0.485	0.1	90.37	*Leptochela gracilis*	19.71
				Alpheus japonicas	11.31
				Acetes chinensis	9.00
				Amblychaeturichthys hexanema	8.55
				Engraulis japonicas	6.30
				Setipinna taty	5.78
				Palaemon gravieri	5.45
				Crangon affinis	4.81
Spring vs Summer	0.449	0.1	95.07	*Engraulis japonicas*	23.82
				Oratosquilla oratoria	17.22
				Loligo japonica	9.56
				Crangon affinis	8.22
				Amblychaeturichthys hexanema	4.84
				Setipinna taty	4.69
				Enedrias fangi	4.65
Spring vs Autumn	0.369	0.1	89.81	*Leptochela gracilis*	15.11
				Crangon affinis	13.55
				Enedrias fangi	7.47
				Amblychaeturichthys hexanema	7.01
				Oratosquilla oratoria	6.87
				Liparis tanakae	5.84
				Philine kinglipini	5.46
				Alpheus japonicas	5.41
				Engraulis japonicus	5.23
Summer vs Autumn	0.359	0.1	92.29	*Engraulis japonicas*	24.26
				Oratosquilla oratoria	16.48
				Loligo japonica	9.74
				Amblychaeturichthys hexanema	9.52
				Leptochela gracilis	9.02
				Setipinna taty	6.27

Ave. Diss., average dissimilarity; Cont., contribution

Vector overlay of Pearson correlations of eight dominant species revealed that vectors of four species (*Engraulis japonicas*, *Oratosquilla oratoria*, *Loligo japonica* and *Leptochela gracilis*) pointed towards the sample clouds in summer season (upper right), three species (*Alpheus japonicas*, *Acetes chinensis* and *Palaemon gravieri*) of crustacean towards that in winter season (upper left), and one species (*Crangos affinis*) toward in spring season (lower left) (*Fig. 6b*).

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A simple Pearson correlation among the eight dominant species was summarized in *Table 4* showed a significant correlation during the study period. Among these eight species, only four species showed significant correlations. For example, *Palaemon gravieri* showed a positively significant correlation with *Alpheus japonicus* (r=0.427**, P<0.01) whereas *Loligo japonica* correlated with *Oratosquilla oratoria* (r=0.517**, P<0.01) (*Table 4*).

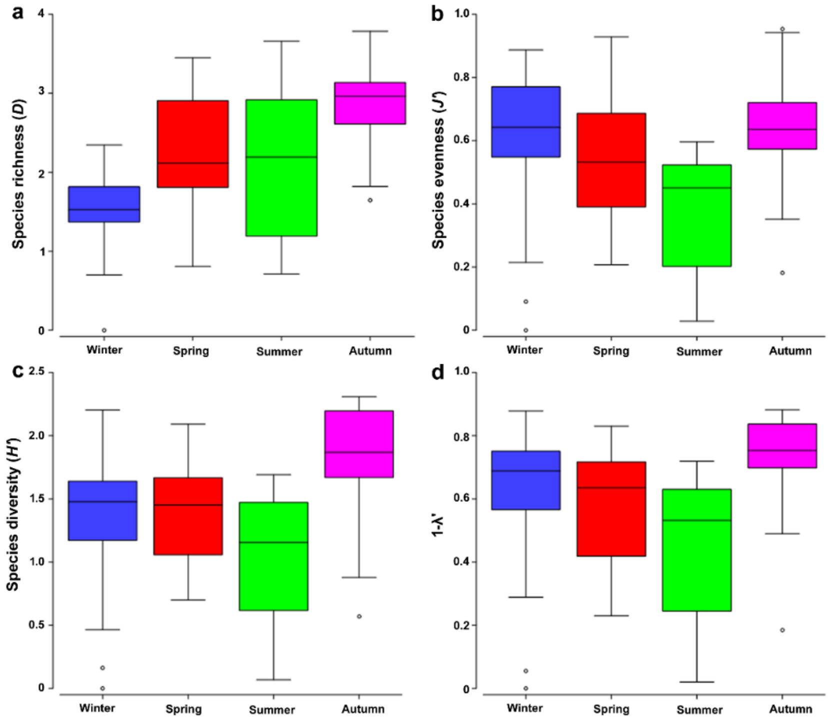

Figure 5. *Variation in species richness (a), evenness (b), diversity (c) and Simpson index (d) during the study period in the Bohai Sea [Whiskers, minimum and maximum; boxes, ±25%; lines, medians]*

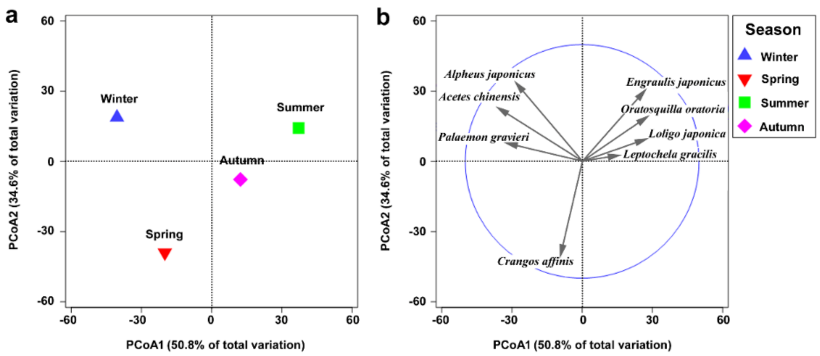

Figure 6. *Principle coordinate analysis (PCoA) on Bray-Curtis similarities from square root transformed species abundance data (a); with vector correlation of eight dominant species with the PCoA axis (b), showing their seasonal variation in community structure of fishery species*

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Table 4. *Pearson correlation coefficients among the eight dominant species during the study period in the Bohai Sea*

	Crangos affinis	*Alpheus japonicus*	*Palaemon gravieri*	*Acetes chinensis*	*Oratosquilla oratoria*	*Loligo japonica*	*Engraulis japonicus*	*Leptochela gracilis*
Crangos affinis	1	-.090	.050	-.066	-.053	-.115	-.056	.005
Alpheus japonicus		1	**.427****	-.073	.117	.142	-.064	-.065
Palaemon gravieri			1	-.040	-.110	-.149	-.119	.058
Acetes chinensis				1	-.031	-.040	-.067	-.058
Oratosquilla oratoria					1	**.517****	-.075	-.110
Loligo japonica						1	-.061	-.129
Engraulis japonicus							1	-.068
Leptochela gracilis								1

Text bold, significant values; **, significant level at 0.05 ($P < 0.01$)

Discussion

The Bohai Sea is considered as an important fishery ground (i.e., spawning, nursing, and fishing) in northern China and the fishery resources have a dynamic nature (Chen et al., 1997; Deng and Jin, 2001). For instance, this shallow water mass used as an important migratory route for many marine species from the Yellow Sea (Liu, 1990). However, the increasing pressure of anthropogenic activities and climate variabilities have already altered the Bohai Sea ecosystem (Lin et al., 2001; Ning et al., 2010; Guo et al., 2013; Liu and Zhang, 2013; Pelling et al., 2013). Investigations have documented that change in climatic conditions and overfishing are the main drivers for fast-paced structural change in the marine ecosystem (Planque et al., 2010; Aschan et al., 2013; Rocha et al., 2015). In this study, we evaluated the characteristics of community structure and dynamics of fishery species in the Bohai Sea.

The Bohai Sea ecosystem is mainly composed of warm water and warm-temperate species. Previous research based on the ecotypes features (i.e., warm-water, warm-temperate, and cold-temperate species), a total of 97 fish species were reported over six decades where a rapid shifting of dominant species occurred (Shan et al., 2016). After 1982, both in the spring and summer season, the species of that ecotype decreased. In an earlier study in the Yellow River estuary of Laizhou Bay in the Bohai Sea, reported that 77 fish species were accounted for where eight pelagic fishes catch contributed more than 10% in every sampling year (Shan et al., 2013). The species composition changed during the survey periods in the Yellow River estuary. Another survey results in the Yellow and

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Bohai Seas, reported a total of 126 species comprising 102 fishes, 17 crustaceans, five cephalopods and two medusas where *Acetes chinensis* was the most dominant in terms of biomass (Chen et al., 1997). Thirty-two crustacean species were enlisted, among them only single species *Crangon affinis* was the dominant species both in Yellow and Bohai Seas during the spring season (Wu et al., 2012). In our study results, *Crangon affinis* was found to be the dominant species which is consisted of previous research results. In addition, our present study found that major dominant species were belonging to crustacean group (*Alpheus japonicas*, 15.34%; *Oratosquilla oratoria*, 11.57%; *Palaemon gravieri*, 10.57%; *Crangon affinis*, 8.85%; *Acetes chinensis*, 7.53%; *Leptochela gracilis*, 7.19%) which clearly indicated the dominant fishery species shift in this ecosystem. The small-sized, pelagic fishes (*Engraulis japonicas*, 6.30%), and crustaceans' species prevailed in the Bohai Sea ecosystem were also reported (Xu and Jin, 2005; Wang et al., 2010; Li et al., 2013).

Based on species richness and total abundance, the maximum was recorded in the summer season. In addition, abundance of eight dominant species also showed similar community variation, thus might be due to variation in ecological conditions among the seasons. Several studies have stated that environmental factors (e.g., temperature, transparency, salinity, dissolved oxygen, nutrients, and water pH) can significantly influence the ecological condition of water in both temporal and spatial scales. Therefore, this ecological condition may shape the fishery species in the Bohai Sea ecosystem (Lin et al., 2001; Jin et al., 2013; Shan et al., 2016). The present study found that there was a significant seasonal shift of dominant fishery species which might be due to fluctuation of water parameters (e.g., temperature) over the decades (Jin 2004; Shan et al., 2016). Many studies showed that recent climate-change-induced variabilities negatively affected the pelagic fishery productivity (Jin et al., 2003; Stige et al., 2006; Perry et al., 2010). The changes in variabilities impede the supply of primary productivity and breakdown the interaction of the trophic levels. So the resultant of this lower food supply can affect the fishery recruitment patterns and dynamics by limiting species migration and shifting keystone species (Zhu and Tang, 2002; Ning et al., 2010) (*Table 5*).

Diversity indices are widely used in the representation of the homogeneity and heterogeneity of ecosystem status, such as existing fishery status on species levels (Shan et al., 2010a, 2011, 2013; Chen et al., 2018). Generally, higher indices values indicate a better environment/ecological quality status and represent a stable ecosystem condition (Chen et al., 1997; Shan et al., 2010b). In the present study we found, species richness, Simpson indices, and diversity were higher in the autumn season which indicated that the ecological condition of water was relatively favorable for fishery species in this season compared to the other three seasons. This variation might be occurred due to the fluctuation of water temperature in the Bohai Sea (Xia and Xiong, 2013). Besides, several anthropogenic stresses (e.g., both municipal/land-based pollution, beerier of natural water flow, coastal reclamation activities) have significant negative effects on fishery species composition and distribution (Zhao and Kong, 2000; Cui et al., 2005; Shan et al., 2013; Yan et al., 2013). In addition, changing of the ecological condition due to algal blooms in winter have a significant negative impact on fishery species was reported in elsewhere

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which is consistent with the present study findings that fishery stock turns over in autumn season just after winter season (Wang et al., 2006; Tang et al., 2010). Thus, the findings of the present study suggest that the community patterns and dynamics structure of fishery species have closed interactions with climate and water ecological conditions in the Bohai Sea.

Multivariate analysis is a more useful tool than univariate analysis for summarizing the interaction of biotic communities with abiotic factors (Anderson et al., 2008; Clark and Gorley, 2015; Chen et al., 2018). Based on these strategies in the present study, PCoA (principal coordinates analysis) and ANOSIM (analysis of similarity) demonstrated that there was an apparent significant seasonal variation in community patterns and dynamics of fishery species in the Bohai Sea ecosystem. This variation is mainly driven by eight dominant species and their mutual interactions (*Table 4*) with typical species (*Table 3*).

Table 5. *Fishery species composition in different studies in the Northwest Pacific Ocean*

Location	Fishes	Crustaceans	Molluscs	Echinod.	Scyphozoan	References
Bohai Sea	43	29	12	3	1	Present study
Bohai Sea	97	-	-	-	-	Shan et al., 2016
Bohai Sea	75	10	6	-	-	Jin, 2004
Yellow River estuary ecosystem in the southern Bohai Sea	77	-	-	-	-	Shan et al., 2013
Yellow and Bohai Sea	102	17	5	-	2	Chen et al., 1997
Yellow Sea	214 (in 1959), 351 (in 1985)	-	-	-	-	Jin and Tang 1996
Middle Yellow Sea of Korea	40	22	17	2	-	Lee et al., 2010
East China Sea and southern Yellow Sea	149 (in autumn), 177 (in spring)	-	-	-	-	Jin et al., 2003
Middle continental shelf of the East China Sea	186	-	-	-	-	Shan et al., 2011

Conclusion

The shallow Bohai Sea ecosystem is used as a unique ground for spawning, feeding, and nursery for many commercial as well as ecological fishery species. The structural patterns and community dynamics of the fishery species in the Bohai Sea are complex and have complicated linked with multiple factors (e.g., pollution, overfishing, climate change, and water ecology). In our present study used a pair trawl survey data to observe the seasonal variation in community patterns and structural dynamics fishery species especially, their abundance, composition, distribution and dominant shift in the Bohai Sea. The community parameters mainly, species richness, diversity, and Simpson indices were higher in the autumn. Multivariate analyses revealed a significant seasonal variation in the fishery community structure patterns and structural dynamics. Our results suggest that ecological conditions may shape the community structure of fishery species in the Bohai

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Sea. Although this study didn't include environmental and climate data, however, such results are important for fisheries assessment and maintaining sustainable fisheries management initiative. Moreover, further studies on the fishery community patterns based on climate and environmental observations are needed to verify this outcome.

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