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Study on fish life history traits and variation in the Taiwan Strait and its adjacent waters

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Abstract

Large portions of the world's fishery resources are overexploited. Life history traits of fish species are important indicators to reveal different life history strategies and to indicate population responses to fishing pressures. For this study, empirical data on fishing grounds located in the coastal area between Fujian Coast and Taiwan Island were collected. These areas have experienced severe overfishing in the past 30 years, leading to changes in the structure and function of the fish communities. Fifty-one commercial fish species in this fishing ground were selected to study the life history traits. Using the life history traits, all the species were grouped into five different life history strategies by principle component analysis. More than 60% of the species were categorized in Group 5 that was similar to r-strategists. Twenty-five commercial species were selected for further analysis of changes in life history variables, and to discuss the population responses to exploitation. Results showed that most of the species appeared to become smaller size, shorter life, earlier maturation and faster growing under long-term exploitation. The exploitation rate of each species was also calculated to further discuss the impacts of fishing pressures to fish populations. Four species were found with the severest changes on life history traits indicating some of the species might be more susceptible to exploitation. This study on fish life history traits and their long-term variations under fishing pressures could provide important scientific implications for fishery management and conservation.

Key words: life history traits, fish life history strategy, fishery exploitation, the Taiwan Strait

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1 Introduction

Coastal and marine fishery resources have experienced substantial reductions in the abundance as well as changes in species composition and the ecological structure of fish communities (Pauly et al., 2002; FAO, 2012). Typically, fish populations tended to be dominated by short living species instead of long living species and companied with a shift in size composition (Ward and Myers, 2005). In heavily exploited populations, fish life history traits changes have been observed (Sharpe and Hendry, 2009), and their life history strategies also switched over time (Luo, 1992; Luo et al., 1993; Du et al., 2011). It is thus acknowledged that life history traits, such as age, size and growth rate, are underlying determinants used to explain and predict the response of different species to pressures, such as exploitation pressure, climate change, etc. (Jennings et al., 1998; Palumbi, 2004; Claudet et al., 2010; Zhou et al., 2010). Previous studies also showed that life history traits of fishes were strongly correlated with their extinction risks and recovery potential (Smith et al., 1998; Stevens et al., 2000; Denney et al., 2002; Reynolds et al., 2005; Hutchings et al., 2012). Studies on fish life history traits and variation therefore are not only an approach to explore the impact of exploitation, but also could contribute to fisheries management and conservation.

There has always been a concern about fish populations in the Taiwan Strait and its adjacent areas. Series of studies on ecological parameters and population dynamics of single or multiple fish species have been conducted in recent years (Du et al., 2008; Chen et al., 2010; Lu and Du, 2008; Lu et al., 2008; Du et al., 2010; Du et al., 2011). However, comprehensive analysis and comparison of life history on massive populations has been relatively rare (Lu et al., 1999a). In this study, we focused on the commercial fish species in this area, and collected fish life history information including size, growth, maturation and life span to analyze life history strategies of different species as well as to observe the variation of fish life history traits under exploitation. The study results could provide important implications for local fishery management.

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2 Materials and methods

2.1 *Study area*

The coastal area between the coastlines of Fujian and Taiwan is the main fishing zone for Fujian Province with rich fishery resources, in which three main fishing grounds are located from the North to South. These are the East-Fujian Fishing ground, Middle-Fujian Fishing ground, South-Fujian and Taiwan bank fishing ground (Fig.1). The area currently provides more than 1.6 million tonnes of fishery resources annually, accounting for 80% of the total fishery production in Fujian Province. The livelihood of nearly one million fishermen depends on the fishing area's proper functioning (Fujian Provincial Bureau of Statistics, 2012). However, it has been experiencing severe overfishing in the past 30 years (Lu et al., 2005). With an abundance of fish species and high exploitation pressure, this area thus could serves as a suitable case study for an analysis of fish life history variations.

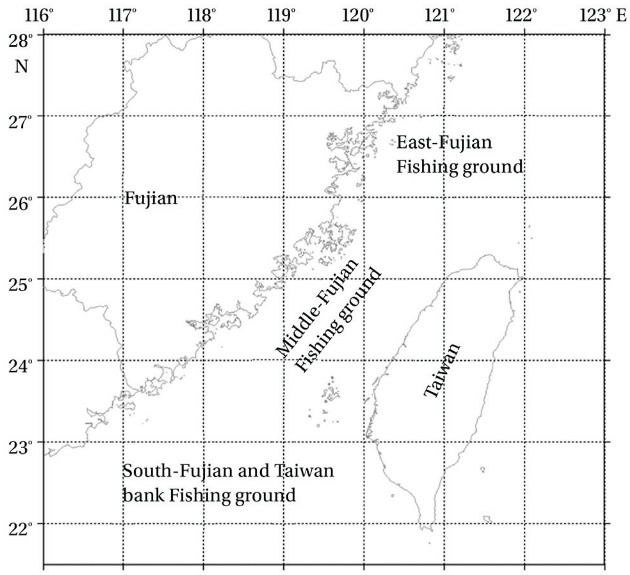

Fig. 1. Distribution of three fishing grounds between the Fujian coast and Taiwan Island.

2.2 *Data collection*

Current and historical fish life history information on a total of 55 populations of 51 commercial fish species in the three fishing grounds was collected. Current data on 29 populations of 26 species were collected from inshore random trawl surveys conducted from 2001 to 2006; and current data on 26 other populations of 25 species were collected from Fujian fishery investigations conducted by Fisheries Research Institute of Fujian during the same period (see Appendix A 1). Historical data on 26 populations of 23 important commercial species among them were summarized from published literatures and records (Lu et al., 1999a; Lu et al., 1999b). Based on the current data, five ecological parameters were selected for the life history strategies grouping:

(1) asymptotic (maximum) length: L_∞ *,

(2) asymptotic (maximum) weight: W_∞ *,

(3) maximum age in years : *ma*,

(4) age at sexual maturity: *asm**,

(5) growth coefficient: Von Bertalanffy growth coefficient *k**.

Four of the life history traits (labeled by *) were determined from the Von Bertalanffy growth equation:

$$L_t = L_\infty \times \left(1 - e^{-k(t-t_0)}\right). \quad (1)$$

According to the limited historical data, four of the life history traits were selected for comparisons of historical and current data in 26 fish populations. Three of them (labeled by *) were used for variation study:

(1) maximum age*,

(2) measured maximum length*,

(3) growth coefficient (*k*)*,

(4) minimum size at maturity.

2.3 *Data analysis*

A principal component analysis (PCA, SPSS 16.0) was conducted on current data for 55 fish populations containing five life history variables to examine the associations between the variables and to categorize the species.

To further explore the changes of life history traits, another PCA was conducted on both historical and current data for total 77 fish populations (22 populations with historical data and 55 populations with current data) containing three life history variables.

The rate of exploitation (*E*) is a key variable to represent fishing pressure. It is the quotient between fishing and total mortality (Roberson and Chapman, 1961):

$$E=F/Z. \quad (2)$$

The fishing mortality rate (*F*) is calculated by the difference between total mortality (*Z*) and natural mortality (*M*) from the equation:

$$F=Z-M. \quad (3)$$

The natural mortality *M* is calculated by using Pauly's *M* empirical equation (Pauly, 1984):

$$\ln M = -0.006\,6 - 0.279 \ln L_\infty + 0.654\,3 \ln k + 0.463\,4 \ln T. \quad (4)$$

Total mortality (*Z*) is calculated by using the Roberson and Chapman's survival rate equation (Robson and Chapman, 1961):

$$Z = -\ln S = T / \left[\sum N + (T-1)\right]. \quad (5)$$

In Eqs (4) and (5), $T=N_1+2N_2+3N_3+\cdots+iN_i$, *S* is survival rate, depends on the age distribution of fish, $\sum N = N_0+N_1+N_2+N_3+\cdots+N_i$, N_0 is the number of fishes at initial marking age, N_1 is the number of fishes at second marking age and so on.

3 Results

3.1 *Habitat distribution*

Amongst the 51 species (including five families, 24 genera) we collected, there were 24 surface and mid-water pelagic species (Nos 1–26), 8 near demersal species (Nos 27–35) and 19 demersal species (Nos 36–55) (See Appendix 1).

3.2 *Life history grouping*

The results of PCA on a 55 population data set showed that the first two components (PC1, PC2) were significant and accounted for a total of 83.60% of the total variance (Table 1). PC 1 was mostly influenced by asymptotic length, asymptotic weight, maximum age, and age at maturity; PC 2 was mostly influenced by the growth coefficient (*k*).

The results (Fig. 2, Table 2) also showed that the major commercial fish species in the Taiwan Strait and its adjacent waters can be categorized into five life history groups. Most of the species were in Group 4 and Group 5.

Group 1 has only one near demersal species and two demersal species, which could be categorized as relatively large in size, long-lived, mature at later ages, slow growing.

Group 2 has only one near demersal species and could be categorized as small in size, short-lived, mature at early ages, fast growing.

Table 1. Variable loadings for significant principal components from PCA for 55 fish populations datasets based on five life history variables

Life history traits	Component	
	PC 1	PC 2
L_∞	0.901 767 9	0.014 054 3
W_∞	0.931 356 5	0.117 573 6
K	−0.657 003 5	0.704 787 4
Maximum age	0.888 939 2	0.003 972 4
Age at sexualmaturity	0.749 908 8	0.449 841 3

Table 2. Grouping results of 55 populations by PCA

Group	Number of species			
	Pelagic species	Near demersal species	Demersal species	Total
Group 1	–	1	2	3
Group 2	–	1	–	1
Group 3	2	–	1	3
Group 4	1	2	6	9
Group 5	21	4	10	35

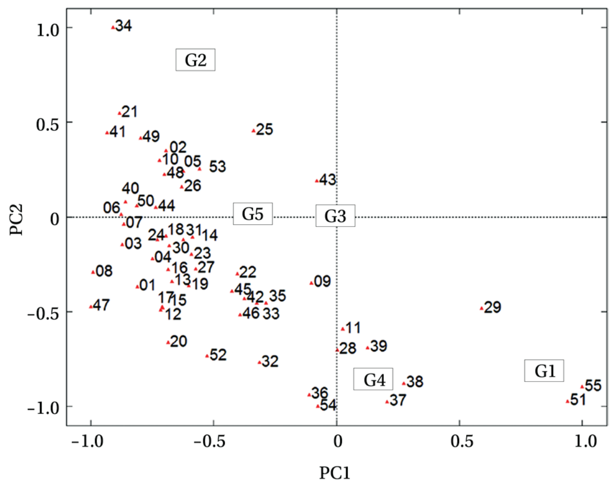

Fig. 2. Plot of standardized scores from the significant components of PCA on five life history traits of 55 fish populations. Positive scores on PC1 represent species that are large in size, long-lived, mature at later ages. Positive scores on PC2 represent higher growth coefficient.

Group 3 has two pelagic species and one demersal species, which could be categorized as medium in size, medium-lived, mature at mid ages, mid-range for growing.

Group 4 is dominated by near demersal and demersal species and could be categorized as medium in size, medium-lived, mature at mid ages, slow growing.

Group 5 has the largest number of fish species. arly half of the fish species belong to this category. This group is dominated by pelagic species and could be categorized as relatively small in size, short-lived, mature at early ages, mid-range in terms of its growth.

3.3 *Variations of life history traits of 26 populations of 25 species*

To examine the fish population responses to long-term fishing pressures and environmental changes, 25 commercial species out of the 51 species which have most historical available data of life history traits for comparisons were selected. The results (Table 3) showed that almost all the species presented an increasing trend in growth (except No. 1 *Sardinella aurita*), and a decreasing trend either in size or in age (except No. 34 *Sillago sihama* and No. 52 *Parargyrops edita*). For 16 species with available historical and current data on size at maturity, it could be seen that all the species' female and male maturity sizes had decreased. The PCA result (Fig. 3) showed that almost all the 22 species shifted from long-lived, large in size and slow growing to short-lived, small in size and fast growing (from red triangles to black dots). The distances between two same species were calculated based on the PCA result (Table 4), in which the longer distance represented the greater changes of life history traits. No. 49 *Larimichthys polyactis* had the longest distance and other three species No. 35 *Tentoriceps cristatus* No. 37 *Saurida tumbil* and No. 39 *Saurida undosquamis* also had relative longer distances between the historical data and current data. The only one species from Group 3 showed the shortest distance between the historical and current data of life history traits. In addition, it could be found that only two species (No. 24 and No. 31) showed a slightly increasing trend in size and age, and only one species (No. 1) showed a decreasing trend in growth rate, while the others all showed a reverse trend (Table 4).

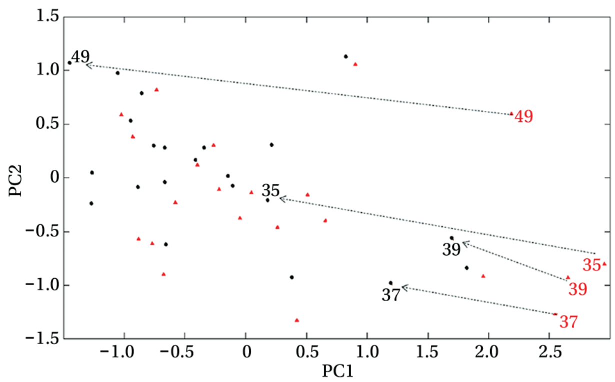

Fig. 3. Plot of standardized scores of 22 species (labeled by * in Table 3) from the significant components of PCA on three life history traits of 77 fish populations (including current data of 55 populations and historical data of 22 populations).The red triangle represents the historical data; the black dot represents the current data. PC1 is most influenced by maximum length, maximum age, with positive scores repre-senting species that are large in size, long-lived; PC 2 is most influenced by growth coefficient (k), with positive scores representing fast growing.

3.4 *Exploitation rate*

The exploitation rate is the proportion of the amount of fish or biomass removed by fishing, which could indicate the fishing pressure for each species. In this study, the exploitation rates of nearly half of the species exceeded 50% (Fig. 4); near demarsal species had higher exploitation rate. The average exploitation rate of near demersal and demersal species was higher than the rate of pelagic species.

Table 3. Changes of size at maturity, max size, max age, and growth coefficient (k) in 26 populations

Fish No.	Period	Size at maturity/mm		Max size/mm	Max age	k
		Female	Male			
1*	1979 and 2006	–	–	−25	0	−0.16
2*	1990 and 2002	−1	−2	−5	0	0.07
9	1973 and 2004	−47	−14	−93	−2	0.32
13*	1982 and 2000	–	–	−34	−1	0.06
14*	1978 and 2006	–	–	−21	−1	0.07
15	1978 and 2006	–	–	−11	0	–
16*	1983 and 2000	–	–	4	−1	0.11
17*	1978 and 2006	–	–	−46	−1	0.00
18*	1984 and 2006	–	−241	−8	0	0.13
19*	1982 and 2006	−4	−3	−25	0	0.01
22*	1982 and 2000	−16	−7	−40	−1	0.03
23*	1978 and 2006	−1	−20	−41	−2	0.10
24*	1989 and 2006	−210	−195	17	0	0.15
25*	1982 and 2000	−4	−5	−13	0	0.01
27	1982 and 2002	−7	1	−45	−1	0.34
31*	1982 and 2006	−9	−9	9	0	0.03
34	1993 and 2003	–	–	35	0	0.34
35*	1976 and 2006	−63	−43	−251	−3	0.10
36*	1983 and 2005	−37	–	−7	0	0.07
37*	1983 and 2006	–	–	−87	−2	0.05
38	1994 and 2006	–	–	−22	0	0.01
39*	1987 and 2006	–	–	−23	−2	0.06
44*	1977 and 2002	−17	−15	−3	0	0.03
48*	1976 and 2006	−3	−2	−30	−1	0.08
49*	1961 and 2005	–	–	−60	−8	0.08
52*	1976 and 2004	−4	−3	3	0	0.05

Table 4. The distance and changing trends between the historical and current data on life history traits based on PCA result (red arrows represent opposite directions to the primary trend)

Fish ID	Distance	Changing trends		Group	Rank
		Size and age	k		
49	3.669 179	↓	↑	5	1
35	2.837 016	↓	↑	5	2
37	1.383 709	↓	↑	4	3
39	1.028 045	↓	↑	4	4
1	0.916 483	↓	↓	5	5
24	0.896 204	↑	↑	5	6
23	0.809 585	↓	↑	5	7
18	0.769 624	↓	↑	5	8
48	0.768 466	↓	↑	5	9
16	0.725 63	↓	↑	5	10
13	0.704 161	↓	↑	5	11
17	0.692 431	↓	↑	5	12
22	0.678 113	↓	↑	5	13
14	0.676 228	↓	↑	5	14
36	0.403 188	↓	↑	4	15
2	0.390 469	↓	↑	5	16
52	0.279 478	↓	↑	4	17
19	0.166 994	↓	↑	5	18
31	0.166 404	↑	↑	5	19
38	0.157 673	↓	↑	4	20
44	0.148 723	↓	↑	5	21
25	0.106 286	↓	↑	3	22

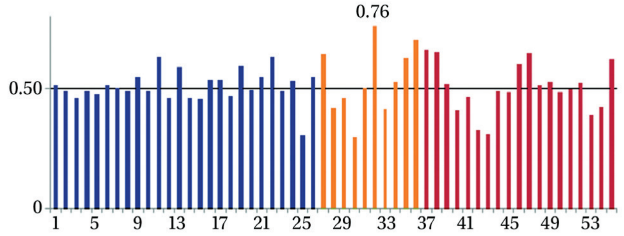

Fig. 4. Exploitation rate of 55 fish populations in the Taiwan Strait and its adjacent waters. Blue represents pelagic fishes, orange near demersal fishes and red demersal fishes.

4 Discussion

4.1 *Life history groupings*

Traditional grouping of life history traits of marine fishes differs from the *r* and *K* strategists (MacArthur and Wilson, 1967; Pianka, 1979), where *r*-strategists are characterized as small in size, and short-lived with early maturation, while *K*-strategists are large in size, and long-lived with late maturation. By further studying life history traits and classification methods of life strategies, scientists have successively proposed the third, fourth and fifth life strategies (Winemiller and Rose, 1992; McCann and Shuter, 1997; King and McFarlane, 2003). In this study, we also identified five life history groups. Due to a limited range of the study area and a lack of fecundity data, the five groups identified differed slightly from previous studies.

According to the grouping results, amongst the total five groups, species in Group 5 took 63.6% of the species we collected, most of which were pelagic fishes (taken up 60% of Group 5), showing that fishes with characteristics of relatively small size, short-lived, mature at early ages, and mid-range in growth composed the major part of the commercial fish stocks in the Taiwan Strait and its adjacent areas. All the pelagic species were in Groups 3, 4 and 5, characterizing with medium or small in size, short or medium-lived, and maturation at early or medium ages. Each group is discussed in the blow.

Group 1 was mostly resembled *K*-strategists, which had bigger sizes, longer generation times, late maturation and slow growth rates. For example, the life span for red seabream (*Pagrus major*) in the Taiwan Strait was 10–14 years, and its sexual maturity age was 3 years. Although having a long life span may reduce the risk of experiencing unfavorable environmental conditions that could cause a loss of stock (Leaman and Beamish, 1984), such species usually have low rates of potential population increase, and appear more vulnerable to fishing pressure, declining more in abundance than other life history groups (Jennings et al., 1998; Jennings et al., 1999).

Group 2 were small in size, had short life-cycles and high growth rates; mostly resembling the *r* or opportunistic strategists (MacArthur and Wilson, 1967). As it matured early and grew fast, this group may have higher resistance to fishing pressures and may be able to recover quickly after a reduction in population. In our study only one species fell in this group -*Silver sillago,* whose age ranged from 0 to 3 years, and the average age was 0.91 years. The growth coefficient (*k*) of *Silver sillago* was 0.66, which was the highest among the 51 fish species.

Group 3 resembled intermediate strategists (Kawasaki, 1983) and the life history traits tended to be mid-range between Group 1 (the *K*) and Group 2 (the *r*) strategists. Their populations could be more resistant to the unfavorable environmental conditions for recruitment than the *K* strategists, but less resistant than the *r* strategists. In our study, *Lethrinus nebulosus* could be considered a typical intermediate strategist, with a life span from 0 to 6 years and a growth coefficient (*k*) of 0.46, reaching sexual maturity after around 1 year.

Group 4, medium in sizes and medium in life cycles, slow growing, were very similar to the *K* strategists. But a separate grouping could be considered as they differ from the *K* strategists with their medium life spans. This group could hence be even more vulnerable to fishing pressures and other environmental changes. Nine species fell in this group with an average life span of 6 years.

Group 5 was characterized by small sizes and short life cycles. They were very similar to the *r*-strategists, but a separate grouping could also be considered as they differ from the *r*-strategists due to their relatively lower growth rates. This group may show less resistance to fishing pressures due to the slower growth. These pelagic species were relatively abundant and stable because of their relative high recruitment in populations, but it may fluctuate with climate–ocean regimes (McFarlane and Beamish, 2001; Brochier et al., 2013). During the period from 1987 until 1998, the largest fishing yield of pelagic species in the South-Fujian and Taiwan Bank fishing ground was in 1987, when a large El Niño event (ENSO) occurred (Fig. 5). The fishing yield then decreased after 1987 and increased again in 1997 when another ENSO event happened. It could be inferred that the population recruitment of these species may have experienced high variability across the regime period.

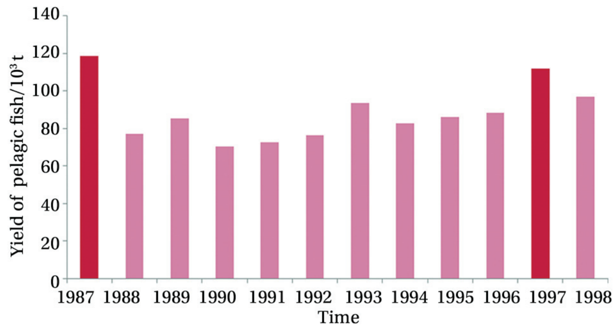

Fig. 5. Yield of pelagic fish in South-Fujian and Taiwan Bank fishing ground (1987–1998). Data source is from Lu et al. (2006).

4.2 *Fish population responses to exploitation*

It is assumed that when fishing mortality (*F*) exceeds the natural mortality (*M*) (where the exploitation rate: E>0.5), the fish stock is overfished (Gulland, 1971; Gulland, 1979). According to our results, nearly half of the commercial fish species were overfished. Indeed, the Fujian coast has been experiencing overfishing for 18 consecutive years since 1994 based on the estimation of the maximum sustainable yield (164.46×10^4 t per year) (Li and Lu, 2008). Current estimated fish productions in all three fishing grounds exceeded the maximum sustainable yields (Lu et al., 2005; Lu et al., 2006) (Fig. 6).

To examine the impacts of exploitation, the changes of exploitation rate from historical data to current data of 22 species were examined (Fig. 7). No significant correlation had been found between the increase of exploitation rate and the change of the life history traits. However the shifting trend of life history traits in most species was obvious. It infers that historical exploitation rates might be already too high for many fish species in these fishing grounds.

Besides, according to Table 4, life-history characteristics of the 26 fish populations showed a general increase trend in growth rate and a decline trend in size, age and size at maturity, indicating that overexploitation could cause comprehensive changes of fish life history strategies (Rochet, 1998; Sharpe and Hendry, 2009). Four demersal and near demersal species had experienced severest changes of life history traits: *Larimichthys polyactis*, *Tentoriceps cristatus,* S*aurida tumbil* and *Saurida undosquamis*, dicaing some of the species might be more susceptible to exploitation (Unwin et al., 1999; Jennings et al., 1998). The distance of all these four species showed in PCA results is more than 1.0, based on the historical data these four species might be grouped into the *K* strategists (Group 1) (Lu et al., 1999b; Chen et al., 2010; Chen et al., 2012).

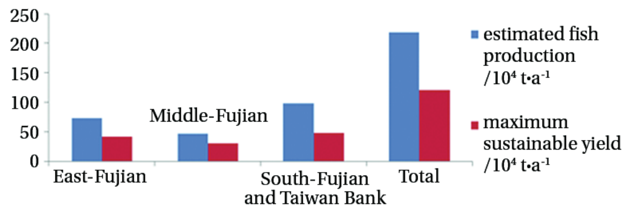

Fig. 6. The comparison of fishing production versus maximum sustainable yield of three fishing grounds in the Taiwan Straits and its adjacent waters.

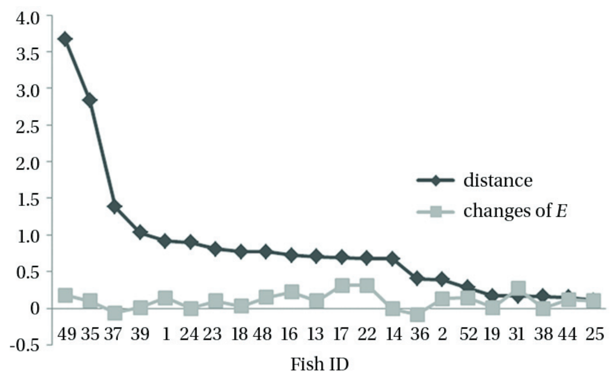

Fig. 7. The distance and the increase of *E* from historical data to current data of 22 species.

Here takes the yellow croaker (No. 49, *Larimichthys polyactis*) as a typical example. It was categorized into Group 5 with current life history traits of small size, short-lived, early maturation and mid-growing. However, the historical traits tended to be large size, long-lived, late maturation and slow growing (Fig. 8), which might be categorized in Group 1. Possible reasons could be that overfishing caused large decreases in Yellow croaker population with increasing numbers of younger and smaller fishes captured (Chen et al., 2010). As a result, less fish survived to be long-lived. This may also cause a change of the growth rate and the recruitment process. For instance, decreased number of big-size individuals may reduce the competition for food and spaces, leading an increase of the growth rate. It is however important to note that the change of life history traits may not be due to the fish's adaptive strategy to environmental pressures, which could also be the passive response of this population to environmental changes in a short period, from which one could infer that this fish population could be restored to its original life history traits by some conservation strategies.

Although the time period was too short to conclude the changes of fish life history strategy in response to long-term exploitation, the observed changes of life history traits indicated that these species might change their life strategies under 30 year's over exploitation. The general trend of life history traits was changing from large size, long life, late maturation and slow growing to small size, short life, early maturation and fast growing. This trend could also explain our grouping results based on current data-most of the species fell in Group 5 resembled the *r*-strategist, while only very few species were in Group 1 (resembled the *K*-strategist). These results are consist with some previous studies that large or slow-growing species with late maturity often decline more rapidly under fishing and environmental pressures compared to those smaller and faster-growing species (Adams, 1980; Roff, 1984; Jennings et al., 1998).

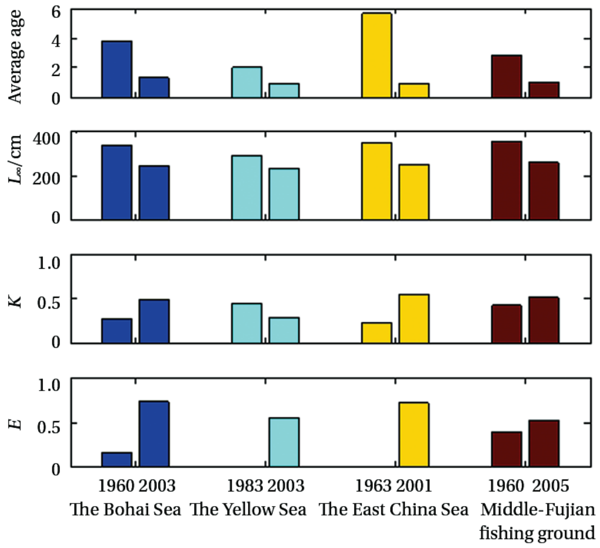

Fig. 8. The changes of three life history traits (age (average age), length (L_∞ and growth rate (k)) and exploitation rate (E) of the yellow croaker (*Larimichthys polyactis*) in four sea areas of China's coast. Data source is from Chen et al. (2010).

In addition, our interpretations of the life history trends were subject to the available historical data. Most of the species analyzed were currently categorized in Group 4 or 5. Only one species (*Auxis thazard thazard*) was from Group 3, and showed the smallest changes between historical and current ecological characteristics (Table 4). Its historical and current exploitation rate was 0.21 and 0.31 respectively, which was also very low compared to other species. The stable life history traits of *Auxis thazard thazard* suggest that its life strategy (Group 3) may be adaptive to the relative low exploitation rate.

4.3 *Fish life history traits and fishery management strategies*

Since it is asserted that fishing pressure is playing a major role in the life history changes observed in commercial fish stocks (Sharpe and Hendry, 2009), the use of life history traits could be an approach to manage and conserve multiple fish species in an ecosystem context (Pauly et al., 2002; King and McFarlane, 2003; Pikitch et al., 2004; Claudet et al., 2010). However, very few empirical studies have been conducted to link life history traits to ecosystem-based management (Claudet et al., 2010). Given the fact that species with different life history traits are in different susceptible level to exploration, we suggest that different management strategies could be proposed to different groups. For example, for Group 1 the maintenance of a proper age-structure in a spawning stock biomass to ensure the reproductive potential would be a key management goal. According to this research species fell in this group are all benthic species, it is crucial to protect their benthic habitats by banning bottom trawling. When regarding Group 5, it was with totally different life history traits and most of the pelagic species fell in this group. Maintenance of a critical spawning biomass would be a key management goal, and control of light fishing should also be an important measure for protection of pelagic fishery resources (Yan, 2006). In addition, in the light of our results, prioritized conservation efforts should focus on those species experienced severest life history changes (species appeared to have longer distance between historical and current data on PCA chart), as these species may be more suscep-tible to fishing pressure and may decline in abundance more rapidly (Adams, 1980; Roff, 1984).

5 Conclusions

Fish life history traits and their variations are important to marine fisheries and marine ecosystem studies. Our study has shown the use of life history traits to group and identify the life strategies of different fish species in the Taiwan Strait and its adjacent waters.It has also revealed the changes of life history traits under long-term overexploitation. Five life history groups of fish species could be identified by PCA analysis. Most of the collected fishes were categorized to life history Group 5, which were dominated by pelagic species and could be characterized as small in size, short-life, mature at early age, and mid-range growth. The comparison of historical and current data showed a general increase trend in growth rate and a decline trend in size, age and size at maturity. Four demersal and near demersal fishes had experienced severest changes of life history traits: *Larimichthys polyactis*, *Tentoriceps cristatus,* S*aurida tumbil* and *Saurida undosquamis*，indicating some of the species might be more susceptible to exploitation. Based on the life history grouping and variation analysis, specific fishery management strategies were proposed to different groupings and species. However, the responding mechanism for the fish populations to the fishing and environmental pressures are not yet to be fully understood. Further studies on life history traits are required both for fisheries research and management.

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Appendix:

Table A1. Life history variables for 51 species analyzed in this study

	No.	Species	Common name	L_∞/mm	W_∞/g	k	Max age	Maturity age
Near demersal species	1	*Sardinella aurita Valenciennes in Cuvierand Valenciennes**	Round sardinella	281.42	287.46	0.31	4.00	0.13
	2	*Konosirus punctatus**	Dotted gizzard shad	242.86	174.87	0.50	4.00	0.97
	3	*Sardinella jussieu*	Mauritian sardinella	182.32	80.46	0.37	3.00	0.21
	4	*Clupanodon thrissa*	Chinese gizzard shad	171.17	74.33	0.35	3.00	1.00
	5	*Setipinna taty**	Scaly hairfin anchovy	203.05	91.94	0.47	4.00	1.58
	6	*Thryssa setirostris*	Longjaw thryssa	191.41	70.34	0.41	3.00	0.48
	7	*Thryssa vitrirostris*	Orangemouth anchovy	184.56	67.77	0.40	3.00	0.07
	8	*Thryssa kammalensis*	Kammal thryssa	140.30	30.10	0.33	3.00	0.05
	9	*Ilisha elongata**	Elongate ilisha	557.61	1 478.84	0.32	6.00	1.47
	10	*Elops machnata*	Tenpounder	361.55	420.83	0.48	3.00	0.35
	11	*Mugil cephalus*	Flathead grey mullet	658.69	3 990.09	0.26	4.00	1.30
	12	*Osteomugil ophuyseni*	Mugil ophuyseni	232.21	158.80	0.29	4.00	0.27
	13	*Decapterus maruadsi 1**	Japanese scad 1	336.56	477.78	0.32	4.00	0.40
	14	*Decapterus maruadsi 2**	Japanese scad 2	307.74	401.98	0.38	5.00	0.70
	15	*Decapterus macarellus**	Mackerel scad	314.15	665.26	0.28	4.00	0.06
	16	*Trachurus japonicus 1**	Japanese jack mackerel	323.25	421.56	0.34	3.00	0.66
	17	*Trachurus japonicus 2**	Japanese jack mackerel	337.20	438.31	0.29	3.00	0.34
	18	*Megalaspis cordyla**	Torpedo scad	387.62	642.59	0.38	5.00	0.03
	19	*Parastromateus niger**	Black pomfret	341.17	1 405.78	0.32	5.00	0.28
	20	*Selar crumenophthalmus*	Bigeye scad	329.22	800.67	0.24	3.00	0.13
	21	*Atropus atropos*	Cleftbelly trevally	267.60	355.87	0.55	3.00	0.35
	22	*Scomber japonicus 1**	Pacific marcerel 1	434.70	1 071.40	0.33	4.00	1.26
	23	*Scomber japonicus 2**	Pacific marcerel 2	381.00	674.86	0.36	4.00	0.61
	24	*Rastrelliger kanagurta**	Indian mackerel	317.97	611.66	0.38	4.00	0.16
	25	*Auxis thazard thazard**	Frigate tuna	481.78	2 256.66	0.52	5.00	0.88
	26	*Pampus argenteus**	Silver pomfret	287.63	627.15	0.45	4.00	0.88
Near demersal species	27	*Psenopsis anomala**	Pacific rudderfish	238.17	506.31	0.34	4.00	1.28
	28	*Glaucosoma hebraicum*	Westralian jewfish	528.42	4 549.20	0.23	5.00	1.13
	29	*Plectorhinchus pictus*	Trout sweetlips	665.46	6 937.92	0.29	8.00	2.77
	30	*Polydactylus sextarius*	Blackspot threadfin	185.81	183.25	0.37	5.00	0.57
	31	*Pennahia argentata**	Silver croaker	299.43	560.23	0.38	5.00	0.39
	32	*Larimichthys crocea 1*	Large yellow croaker 1	555.40	2 300.50	0.21	3.00	0.71
	33	*Larimichthys crocea 2*	Large yellow croaker 2	551.58	2 198.24	0.29	6.00	0.66
	34	*Sillago sihama**	Silver sillago	260.89	153.81	0.66	3.00	0.17
	35	*Tentoriceps cristatus**	Crested hairtail	528.53	1 771.42	0.29	4.00	0.92
Demersal species	36	*Trachinocephalus myops**	Snakefish	431.69	931.45	0.17	6.00	1.18
	37	*Saurida tumbil**	Greater lizardfish	647.57	3 274.79	0.16	6.00	0.81
	38	*Saurida elongata**	Slender lizardfish	566.62	2 172.46	0.19	7.00	1.83
	39	*Saurida undosquamis**	Brushtooth lizardfish	563.06	1 804.98	0.23	7.00	1.97
	40	*Osteomugil strongylocephalus*	Hardhead mullet	196.97	98.66	0.43	3.00	0.31
	41	*Liza carinata*	Keeled mullet	243.84	178.45	0.52	3.00	0.01
	42	*Lethrinus haematopterus*	Chinese emperor	507.34	2 339.40	0.30	5.00	0.47
	43	*Lethrinus nebulosus*	Spangled emperor	584.00	5 083.80	0.46	6.00	1.07
	44	*Upeneus japonicus**	Bensasi goatfish	182.73	131.42	0.42	5.00	0.61
	45	*Parupeneus chrysopleuron*	Yellow striped goatfish	305.39	669.22	0.31	4.00	1.42
	46	*Nemipterus virgatus**	Golden threadfin bream	373.40	967.61	0.28	4.00	1.25
	47	*Teixeirichthys jordani*	Jordan's damsel	125.90	97.01	0.29	3.00	-1.87
	48	*Priacanthus macracanthus**	Red bigeye	273.79	502.89	0.46	4.00	0.75
	49	*Larimichthys polyactis**	Yellow croaker	261.17	217.28	0.51	3.00	0.66

to be continued

Continue from Table A1

No.	Species	Common name	L_∞/mm	W_∞/g	k	Max age	Maturity age
50	*Pennahia macrocephalus*	Big-head pennah croaker	234.81	316.98	0.42	3.00	0.54
51	*Triso dermopterus*	Oval grouper	721.72	8 801.93	0.16	13.00	1.71
52	*Parargyrops edita**	Parargyrops edita	268.40	503.55	0.22	5.00	0.34
53	*Acanthopagrus latus*	Yellowfin seabream	346.26	1 127.14	0.47	4.00	0.73
54	*Acanthopagrus schlegelii schlegelii*	Blackhead seabream	536.75	3 526.18	0.15	10.00	-0.56
55	*Pagrus major*	Red seabream	721.80	8 933.01	0.18	14.00	2.40

Notes: * means 29 populations measured by inshore random trawl surveys from 2001-2006. Species labeled by 1 (e.g., *Scomber japonicus 1*) belong to the population in East China Sea; species labeled by 2 (e.g., *Decapterus maruadsi 2*) belong to the population in South Fujian-East Guangdong.