



Assessments of 16 Exploited Fish Stocks in Chinese Waters Using the CMSY and BSM Methods

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Sixteen marine fish species (populations) exploited by Chinese fisheries were assessed, using published time series of catch and the CMSY and BSM methods. Given the catch times series as inputs, some ancillary information and reasonable constraints, carrying capacity, maximum sustainable yield, and likely time series of biomass and exploitation rate were estimated. The results show that one (7%) of the assessed species was severely depleted, four species (27%) were fully/overfished, six (40%) were outside of safe biological limits, one species (7%) was recovering and three species (20%) were in a healthy state at the end year of their assessment. However, one species, Pacific sardine (*Sardinops sagax*), could not be assessed using CMSY, as the exceedingly large fluctuations of its biomass were mainly environmentally driven. These results correspond with previous knowledge on the status of fish populations along the coast of China, where overfishing is rampant. Based on these assessments, some of the benefits that would result from a reduction of the excessive fishing effort are outlined.

Keywords: data-poor fisheries, Chinese coastal fisheries, biomass declines, CMSY, stock assessments

INTRODUCTION

China is the country with the world's largest marine fisheries catch (FAO, 2018). It is widely agreed that China's domestic fisheries resources are overexploited (Shen and Heino, 2014). However, it seems that overfishing has gradually changed the structure and function of marine ecosystems of China's coastal seas (Zhai and Pauly, 2020) and that the state of its domestic resources is the main reason for its current emphasis on distant-water fishing (Mallory, 2013).

China's fisheries management system has been gradually improving since the 1980s (Huang and He, 2019). Its most powerful regulations are the "double control" system and summer fishing moratoria (Shen and Heino, 2014). The former are regulations of both the total number of marine engine-powered fishing vessels and their total engine power; the latter have been implemented since 1995 and extended from 3 to 4 months and more in many areas (Ministry of Agriculture and Rural Affairs of the People's Republic of China [MARA], 2018). Also, some other regulations and programs are being implemented including vessel buyback, alternative employment opportunities for fishers (Song, 2007) and a 10 year fishing ban in the Yangtze River Basin (Ministry of Agriculture and Rural Affairs of the People's Republic of China [MARA], 2019).

China has carried out a large number of fishery resource surveys and stock assessment work in recent years, but still faces difficulties due to a lack of historical data. Thus, there are still deficiencies regarding China's fish stock assessments: the range of species covered by assessments is narrow, evaluation methods are limited and the results are not usually expressed as B/B_{MSY} , i.e., the ratio of stock biomass to the biomass that can produce the maximum sustainable yield (MSY) or other management-relevant indicators. Until recently, very few stock assessments were conducted that allowed for estimating the potential for stock rebuilding (Villasante et al., 2013), although this dire situation is now being overcome (see Zhai and Pauly, 2019; Ji et al., 2019; Liang et al., 2020a,b; Wang et al., 2020; Zhang et al., 2020).

Here, the newly developed CMSY method (Froese et al., 2017), catch time series and some **Supplementary Information** are used to infer likely biomass trajectories for 16 species of exploited fish along Chinese coastlines. This method was shown to be adequate for the assessment of hundreds of fish stocks in and around Europe (Froese et al., 2017, 2018; Demirel et al., 2020). Moreover, a number of contributions show that the method can be used for stock assessment in China (Ji et al., 2019; Liang et al., 2020b; Wang et al., 2020).

Also, a Bayesian state-space implementation of the Schaefer model (BSM; Froese et al., 2017) is applied here with the same catch time series and priors, and additional catch/effort (C/f , or CPUE) and/or biomass data, to assess the biomass and exploitation rate, and thus to assess the stock status and extent of overfishing in Chinese and adjacent waters. This contribution is a further example of the study of data-poor fisheries and our results provide information toward a science-based management of China's fisheries.

MATERIALS AND METHODS

Data Sources

The main features of the catch time series and additional information available for 16 fish populations investigated here are given in **Table 1**, while the data sources are shown in **Supplementary Table 1**. All species investigated here are important commercial fish in China since the 1950s that have more than 10 years of catch data.

The CMSY and BSM Methods

The principle of the CMSY method is that, given catch time series and using a Monte Carlo approach, multiple biomass trajectories of the biomass of the stock in question are traced, and the parameters retained that generated the biomass trajectory (or trajectories) that is (are) compatible with the time series of catches, and a number of constraints (Froese et al., 2017). Here, "compatible" means that, among other things, the stock does not crash, i.e., its biomass does not drop to zero.

When, as is the case here, relative abundance data, such as CPUE or spawning stock biomass (SSB), are also available, a Bayesian state-space implementation of the Schaefer production model (BSM; Millar and Meyer, 1999) is applied to estimate the

intrinsic rate of population growth (r) and unexploited stock size (or carrying capacity; k) of each stock (Froese et al., 2017).

The CMSY and BSM methods are based on the logic of the surplus-production model of Schaefer (1954, 1957). Thus, they assume that from 1 year (t) to the next ($t + 1$), the biomass (B_t) follows the equation:

$$B_{t+1} = B_t + r(1 - B_t/k)B_t - C_t \quad (1)$$

where r is the intrinsic rate of population growth, k the carrying capacity, and C_t is the catch in year t .

However, Eq. (1) is slightly modified when the biomass falls below $0.25k$, to allow for depensation or reduced recruitment when stock size is severely depleted (Froese et al., 2017):

$$B_{t+1} = B_t + (4rB_t/k)(1 - B_t/k)B_t - C_t \mid B_t/k < 0.25 \quad (2)$$

where the term $4rB_t/k$ ensures a linear decline of recruitment below half of the biomass capable of generating MSY.

Prior Information

The R code implementing the CMSY method incorporates a routine which estimates wide (uniform) priors for k (Froese et al., 2017), whose output were here accepted:

$$k_{low} = \max(C)/r_{high}; \quad k_{high} = 4\max(C)/r_{low} \quad (3)$$

where k_{low} and k_{high} are the lower and upper bounds of the prior range of k , $\max(C)$ is the maximum catch in the time series and r_{low} and r_{high} are the lower and upper bound of the range of r -values that the CMSY method explores. This is expressed by

$$k_{low} = 2\max(C)/r_{high}; \quad k_{high} = 12\max(C)/r_{low} \quad (4)$$

where the variables and parameters are defined as in Eq. (3).

As stated in Froese et al. (2017), when running the BSM method, the estimated standard deviation of r in log-space is described by a uniform distribution between 0.001 irf and 0.02 irf by

$$\text{irf} = 3/(r_{high} - r_{low}) \quad (5)$$

where irf is an inverse range factor to determine r range, and r_{high} and r_{low} is provided in **Table 2**.

The k estimation by BSM also assumes that k has a log-normal distribution, while the mean of k provides the reasonable central value. The standard deviation of k is assumed to be a quarter of the distance between the central value and the lower bound of the k -range (McAllister et al., 2001).

Additionally, the BSM method allows the estimation of the catchability coefficient q , which relates biomass to CPUE, when the latter is available. For this, priors are defined as

$$q_{low} = 0.25r_{pgm}CPUE_{mean}/C_{mean}; \quad q_{high} = 0.5r_{high}/CPUE_{mean} \quad (6)$$

where q_{low} and q_{high} are the lower prior and higher prior for the catchability coefficient respectively; r_{pgm} is the geometric mean of the prior range for r ; $CPUE_{mean}$ is the mean CPUE over the last 5 or 10 years; C_{mean} is mean catch over the same period.

For stocks with low recent prior biomass, the ranges of multipliers are 0.25–0.5 for q_{low} and 0.5–1 for q_{high} .

TABLE 1 | Summary of data available for the stock assessments presented here (the data themselves and data sources are presented in **Supplementary Table 1**).

Scientific name (common name)	Region	Catch	Additional data
<i>Clupea pallasii</i> (Pacific herring) ^{1,2}	Chinese waters ³	1989–2014	CPUE (2001–2014)
<i>Sardinops sagax</i> (Pacific sardine)	Sea of Japan and ECS	1951–2006	None
<i>Engraulis japonicus</i> (Japanese anchovy) ^{1,2}	Chinese water	1989–2014	CPUE (1979–1997)
<i>Coilia mystus</i> (Osbeck's grenadier anchovy) ²	Yangtze River and Estuary, and ECS	1960–2007	CPUE (1995–1999)
<i>Ilisha elongata</i> (elongate ilisha) ^{1,2}	Chinese water	1978–2014	CPUE (2001–2014)
<i>Decapterus muroadsi</i> (amberstripe scad) ²	ECS	1973–2013	CPUE (1998–2013)
<i>Scomber australasicus</i> (spotted mackerel)	ECS	1992–2013	SSB (2006–2010)
<i>Scomberomorus niphonius</i> (Japanese Spanish mackerel)	ECS	1984–2013	None
<i>Trichiurus lepturus</i> (largehead hairtail) ²	Chinese waters	1956–2014	CPUE(1998–2013)
<i>Branchiostegus japonicus</i> (horsehead tilefish)	ECS	1985–2013	None
<i>Larimichthys crocea</i> (large yellow croaker) ²	ECS	1956–2002	CPUE(1990–2002)
<i>Larimichthys polyactis</i> (yellow croaker) ²	Chinese waters	1956–2014	CPUE(2010–2014)
<i>Pagrus major</i> (red seabream)	East China Sea	1969–2013	SSB (1986–2013)
<i>Paralichthys olivaceus</i> (Japanese flounder)	East China Sea	1975–2013	SSB (1993–2013)
<i>Thamnaconus modestus</i> (bluefin leatherjacket) ²	YS and ECS	1973–2000	CPUE (1980–1993)
<i>Muraenesox cinereus</i> (pike eel) ²	Chinese and Taiwan waters	1979–2017	CPUE (2005–2017)

¹The catch data of *E. japonicus* in 1992, of *C. pallasii* in 2006, and of *I. elongata* in 1995 and 2006 were interpolated from the two adjacent years' catches. ²The CPUE is corrected by 2% each year on account of technical development (Palomares and Pauly, 2019). ³"Chinese" refers to "Chinese mainland" in this study; SSB, spawning stock biomass; YS, Yellow Sea; ECS, East China Sea.

The intrinsic rate of population growth (r) is largely determined by the size and age at first maturity of individuals of the species in question, and FishBase¹ (Froese and Pauly, 2019), based on these and other traits, provides ranges of likely values ("priors") for all fish species (Froese et al., 2000). Also, a resilience classification based on the stock fecundity was proposed by Musick (1999). The available resilience ranges and those selected for the 16 stocks studied here are given in **Table 2**.

Additionally, two constraints are required for the CMSY method, i.e., the fraction of carrying capacity that the biomass was exhibiting just before the first annual catch in the available time series is subtracted (B_{start}/k ; see Eq. 1) and the fraction of carrying capacity that the biomass reached at the end of the catch time series, again expressed as a fraction of k (B_{end}/k). The first of these constraints is a function of the fishing pressure to which the population (or stock) in question was exposed to prior to the period for which catch data are available, and which would have reduced the biomass below carrying capacity.

¹<http://www.fishbase.org/>

TABLE 2 | Ranges suggested by FishBase (see text footnote 1) for population growth rate (in year⁻¹).

Resilience (r)	Suggested prior	Range assumed for the stocks in Table 1
High	0.6–1.5	<i>E. japonicus</i> ; <i>C. mystus</i>
Medium	0.2–0.8	<i>C. pallasii</i> ; <i>S. sagax</i> ; <i>I. elongata</i> ; <i>D. muroadsi</i> ; <i>S. australasicus</i> ; <i>S. niphonius</i> ; <i>B. japonicus</i> ; <i>L. crocea</i> ; <i>L. polyactis</i> ; <i>P. olivaceus</i> ; <i>T. modestus</i> ; <i>T. lepturus</i> ; <i>M. cinereus</i>
Low	0.05–0.5	<i>P. major</i>
Very low	0.015–0.1	–

Table 3 presents suggested ranges of B_{start}/k and B_{end}/k for the stocks in **Table 1**. Note that for some species that were already exploited in the 1950s, we selected a very low depletion ($B_{start}/k = 0.8-1$) for the start of the series because of the low technology that was deployed at the time (Zhan et al., 1986; Yang, 1988; Zhang and Hua, 1990; Yu and Zheng, 2000; Liu, 2005; Xu and Liu, 2007; Wang et al., 2011; Xu et al., 2014; Yan et al., 2014). For some other species, we selected a low range ($B_{start}/k = 0.4-0.8$), in view of the fact that from the 1970s to the 1990s, a massive increase of fishing effort occurred, and the technological sophistication of that effort also increased (Zhu, 1992; Qiu, 1995; Lu et al., 1998; Bo et al., 2005).

There are two exceptions here, *Larimichthys polyactis* and *Sardinops sagax*, were set at the strong (0.01–0.4) and very strong (0.01–0.2) depletion, respectively (**Table 3**). For *L. polyactis*, the catch of the stock in the final year increased to 2~3 times that of the start year (Lin et al., 2004; Yan et al., 2014). Thus, we have a good reason to assume that *L. polyactis* was already strongly overfished in the mid-1950s.

The B_{start}/k for *S. sagax* was set at a very strong depletion (0.01–0.2; see **Table 3**) to force its biomass at the start of the assessment period to be very low. This biomass subsequently increased due to environmental factors (Wei and Li, 1986; Lluch-Belda et al., 1989), a topic to which we will return.

The second constraint, the expected biomass at the end relative to carrying capacity (B_{end}/k), should be roughly reflective of the fishing pressure which generated the available catch time series. **Table 3** presents suggested ranges of B_{end}/k , i.e., the fraction of the population initially present that is left in the water, set based on the default rules of CMSY method (Froese et al., 2017).

The last constraint, i.e., the ratio of biomass reached during an intermediate year to carrying capacity (B_{int}/k), can be used if such

TABLE 3 | Suggested ranges of the fraction B_{start}/k and B_{end}/k for the biomass depletion before catch data are available*.

Depletion	Suggested prior	Assumed level of prior depletion of the stocks in Table 1	
		B_{start}/k	B_{end}/k
Very low	0.8–1	<i>C. pallasii</i> ; <i>E. japonicus</i> ; <i>C. mystus</i> ; <i>I. elongata</i> ; <i>T. lepturus</i> ; <i>L. crocea</i> ; <i>T. modestus</i> ; <i>S. niphonius</i> ; <i>M. cinereus</i>	–
Low	0.4–0.8	<i>D. muroadsi</i> ; <i>S. australasicus</i> ; <i>B. japonicus</i> ; <i>P. major</i> ; <i>P. olivaceus</i>	–
Medium	0.2–0.6	–	<i>E. japonicus</i> ; <i>I. elongata</i>
Strong	0.01–0.4	<i>L. polyactis</i>	<i>S. sagax</i> ; <i>C. mystus</i> ; <i>D. muroadsi</i> ; <i>T. lepturus</i> ; <i>B. japonicus</i> ; <i>P. major</i> ; <i>T. modestus</i>
Very strong	0.01–0.2	<i>S. sagax</i> **	<i>C. pallasii</i> ; <i>L. crocea</i>

*See **Supplementary Material** to Froese et al. (2017); **A very low range was selected here to enable the CMSY method to simulate the environmentally driven massive increase of the biomass of *S. sagax* in the 1970s and 1980s (see text).

knowledge is available. We set “default” B_{int}/k for all stocks in this study except for *Engraulis japonicus* (Japanese anchovy; int. year is 2009, prior range is 0.2–0.6; Li et al., 2015).

The CMSY method identifies the r and k values generating viable biomass trajectories (if any), then output the geometric means and confidence intervals of these estimates. As well, various parameters that can be derived from r and k , notably $MSY = 0.25r \cdot k$, $F_{MSY} = 0.5r$ and $B_{MSY} = 0.5k$ (Schaefer, 1954; Ricker, 1975) are also estimated.

The BSM method can run with additional constraints, such as SSB or catch/effort (C/f , or CPUE) (Froese et al., 2017), which represent (relative) abundance. In this case, the viable biomass trajectories will take account of the (relative) abundance data, even if they pertain to a shorter period than the catch data (Table 1). In the process, an estimate of the catchability coefficient $q = (C/f)/B$ is also produced as an average for the period with CPUE data (see Eq. 6).

Four of the sixteen stocks in the study, i.e., *E. japonicus*, *Coilia mystus*, *L. polyactis* and *Muraenesox cinereus* with more than one SSB or CPUE time series, we used a routine “Bcrumb,” to interpolate and average SSB or CPUE for them. This routine was developed as a component of JARA (Just Another Redlist Assessment) described in Winker and Sherley (2019). Moreover, considering the technological improvement of the fishery, the CPUE is corrected by 2% increases every year according to Palomares and Pauly (2019), given gear and other technological improvements of the industrial sector.

The ratio B/B_{MSY} in the final year, which is often used to express stock status, is estimated by both CMSY as well as BSM. For management purposes, the more precise results of BSM may be preferred over the results of a CMSY assessment. Table 4 presents suggestion of fish stock status based on B/B_{MSY} and

TABLE 4 | Definition of fish stock status, based on B/B_{MSY} in the final year of a time series*.

B/B_{MSY}	F/F_{MSY}	Stock status
≥ 1	< 1	Healthy stock
0.5–1.0	< 1	Recovering stock
< 0.5	< 1	Stock outside of safe biological limits
0.5–1.0	> 1	Fully/overfished stock
0.2–0.5	> 1	Stock outside of safe biological limits
< 0.2	> 1	Severely depleted stock

*See Froese et al. (2018).

F/F_{MSY} in final year. (Note that $2 \cdot B_{end}/k = B_{MSY}/k$, as MSY is taken at $0.5k$).

RESULTS

Altogether 16 fish populations were analyzed by CMSY method, with 13 also assessed using the BSM methods, as CPUE/biomass data were available for them. The results of estimated r - k for *Scomberomorus niphonius* and *E. japonicus* are shown in Figure 1 as examples, while all other results are shown in Table 5 and Supplementary Figure 1 (except for *S. sagax*).

In Figure 1A, featuring Japanese Spanish mackerel (*S. niphonius*) and Figure 1B, featuring Japanese anchovy (*E. japonicus*), the viable r - k pairs (gray) were obtained by the CMSY method, and the solid crosses identify the most probable r - k pairs, along with their 95% confidence intervals. In Figure 1B, the BSM method used (relative) abundance data (i.e., SSB/CPUE), and the viable r - k pairs it estimated are in black. The dotted cross identifies the most probable r - k pair, and its 95% confidence intervals. The overlaps between the two clouds of dots (and hence the closeness of the two crosses) implies that the results of the two methods are similar, and thus more credible than if they did not overlap.

The biomass trends resulting from the CMSY and BSM analyses are shown in the different panels of Figure 2. In each panel, the key item is the biomass trajectory (solid black line) and its 95% confidence intervals (dotted line). The horizontal dashed line represents B_{MSY} , while the vertical solid lines show the priors on biomass range at the start and end of time series. Finally, the open dots indicate corrected CPUE trends of the 13 stocks for which such data was available.

As shown in Figure 2, the biomass of all species generally declined, although a few species, notably *L. polyactis*, substantially recovered. The mean B/B_{MSY} for 15 stocks is 0.59 ± 0.10 (SE) and mean B_{end}/k is 0.29 ± 0.05 (SE).

The results demonstrate that the exploitation rate (i.e., F) for 9 species of the 15 are higher than F_{MSY} . The average value for 15 species is 1.39 ± 0.26 (SE). The species *Clupea pallasii* have the highest exploitation rate of 4.33 (Table 5 and Supplementary Figure 2).

According to the definition of fish stock status (see Table 4), the average status of China’s coastal fish stock assessed here is fully/overfished. Three of the assessed stocks were healthy, one

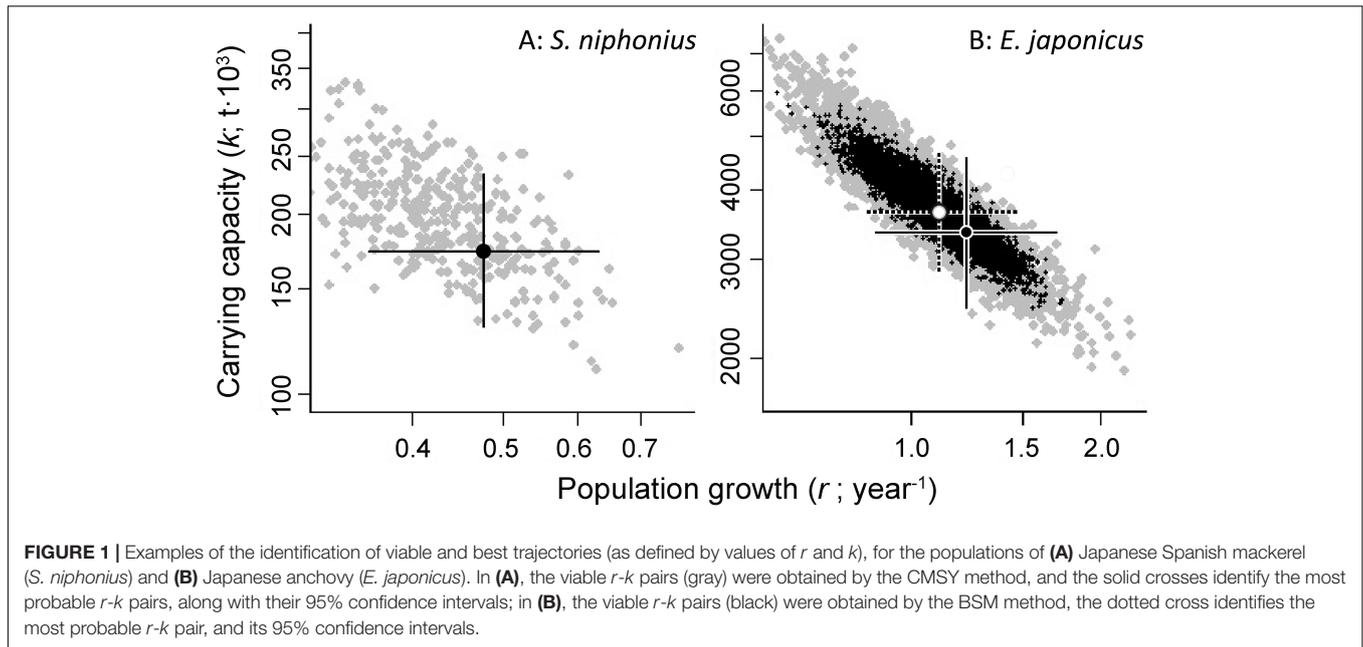


TABLE 5 | Estimates of r , k , MSY , B/B_{MSY} and status as obtained by CMSY and/or BSM method for 15 fish stocks of China’s coastal seas. The result in normal font are based on the BSM method, i.e., they used catch and additional relative abundance data; the results in bold font are only based on catch time series and CMSY*.

Species	r (year ⁻¹)	K (10 ³ t)	MSY (10 ³ t·year ⁻¹)	F/F_{MSY}	B/B_{MSY}	B_{end}/k	Status
mean				1.39 ± 0.26	0.59 ± 0.09	0.29 ± 0.05	
<i>C. pallasii</i> (Pacific herring)	0.48	222	27	4.33	0.27	0.14	Stock outside of safe biological limits
<i>E. japonicus</i> (Japanese anchovy)	1.12	3643	1017	0.68	1.30	0.65	Healthy stock
<i>C. mystus</i> (Osbeck’s grenadier anchovy)	0.71	8	1	0.31	0.55	0.27	Recovering stock
<i>I. elongata</i> (elongate ilisha)	0.80	423	84	1.60	0.56	0.28	Fully/overfished stock
<i>D. muroadsi</i> (amberstripe scad)	0.32	543	44	1.33	0.26	0.13	Stock outside of safe biological limits
<i>S. australasicus</i> (spotted mackerel)	0.61	371	57	1.33	0.67	0.34	Fully/overfished stock
<i>S. niphonius</i> (Japanese Spanish mackerel)	0.48	173	21	1.28	0.48	0.24	Stock outside of safe biological limits
<i>T. lepturus</i> (largehead hairtail)	0.75	6049	1130	1.73	0.56	0.28	Fully/overfished stock
<i>B. japonicus</i> (horsehead tilefish)	0.32	78	6	0.77	0.25	0.13	Stock outside of safe biological limits
<i>L. crocea</i> (large yellow croaker)	0.35	1215	107	1.05	0.17	0.08	Severely depleted stock
<i>L. polyactis</i> (yellow croaker)	0.44	3348	372	0.81	1.19	0.59	Healthy stock
<i>P. major</i> (red seabream)	0.25	108	7	1.51	0.59	0.30	Fully/overfished stock
<i>P. olivaceus</i> (Japanese flounder)	0.50	13	2	0.69	1.14	0.57	Healthy stock
<i>T. modestus</i> (bluefin leatherjacket)	0.33	1963	162	0.67	0.37	0.18	Stock outside of safe biological limits
<i>M. cinereus</i> (pike eel)	0.49	2389	295	2.72	0.48	0.24	Stock outside of safe biological limits

*Pacific sardine (*S. sagax*) is not included here because its dynamics was mainly driven by environmental fluctuations (see text).

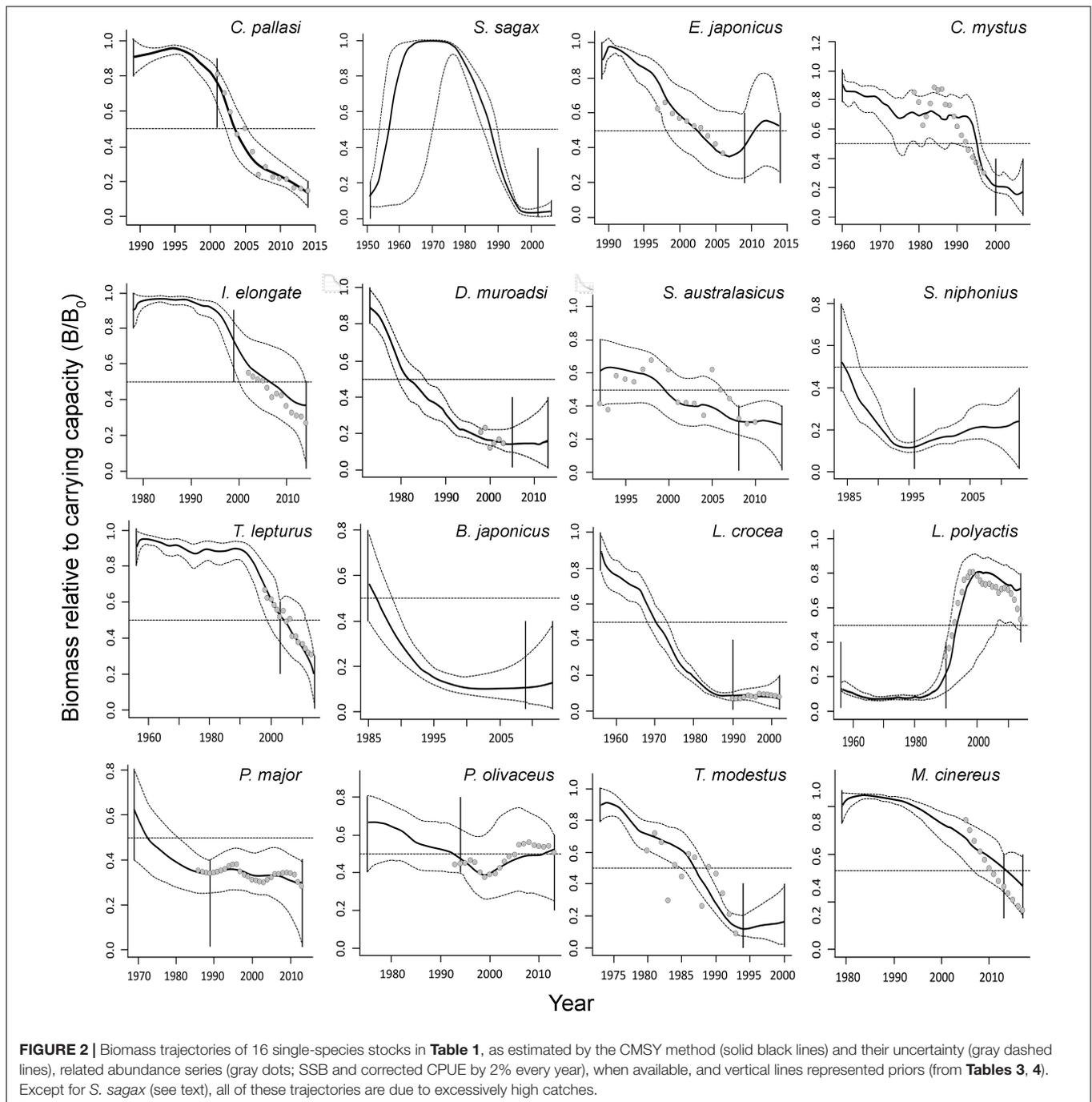
was recovering, six were outside of safe biological limits, four were fully/overfished, one was severely depleted (see Figure 3).

DISCUSSION

Time series of catches such as analyzed here are scarce for Chinese waters; however, the few that are available provided the impression of massive overfishing, consistent with other analyses (Liang and Pauly, 2017b; Zhai and Pauly, 2019; Liang et al., 2020a,b). All of the thirteen stocks with CPUE or SSB included in this contribution were well fitted by the CMSY and BSM methods, i.e., the most likely estimated r - k pair are

included within the 95% confidence intervals of each other (see Supplementary Figure 1). Similarly, Ji et al. (2019) found a good match between the estimates of population parameters of *Trichiurus lepturus* in the Yellow and Bohai Seas obtained by using CMSY and those from the Schaefer and Fox models. Thus, the CMSY method can for assessing data-limited fisheries, although the related BSM methods, which additional information (e.g., CPUE data) produces narrower confidence intervals (Ren and Liu, 2020).

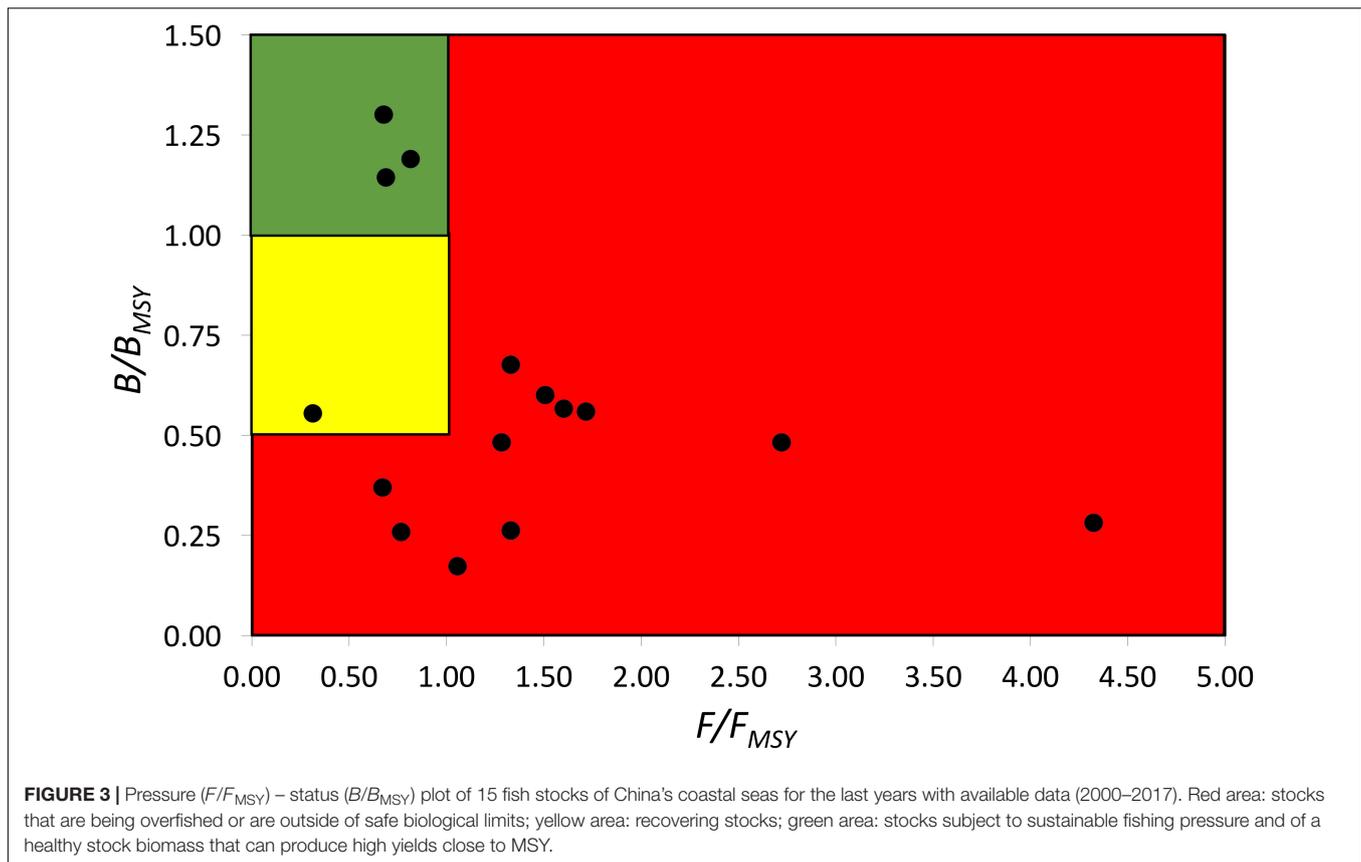
The intrinsic rate of population growth (r) is key in defining the response of populations to challenges such as fisheries (Cheung et al., 2005; Anderson et al., 2008). FishBase (see text



footnote 1; Froese and Pauly, 2019) provides estimated ranges of r for fish populations based on life-history traits of fish populations which are very useful, as they compensate for the lack of estimates from local data.

The uncertainties of catch, SSB or CPUE data, which may result, e.g., from discards not having been considered, or unreported catch issues, will lead to errors in the assessment. In these cases, the local experience of fisheries experts should be accounted for when screening the data sets and results.

The catches of most of the species investigated here exhibited an explosive growth in the 1990s and/or the 2000s, then stagnated and declined. This feature basically coincides with China's fishery development history. Fisheries of China developed gradually from the 1950s to the 1970s, then rapidly in 1980s and 1990s, with its total catch peaking in the 2000s (Anon, 1963-2019; Shen and Heino, 2014; **Supplementary Figure 3**). Even though China's national catch statistics were over-reported in the 1990s, resulting in distortions in the catch and CPUE data (Watson and Pauly, 2001), the rapid growth of China's



overall fishing effort in undeniable, and it had a strong effect on the structure of its coastal ecosystems (Zhai and Pauly, 2019).

Some important fish species, such as *Decapterus muroadsi*, *Branchiostegus japonicus*, and *Larimichthys crocea*, were already strongly exploited in the 1950s. Thus, the stock of large yellow croaker (*L. crocea*), a prized species in China, was quickly depleted when China developed its industrial fisheries; it finally collapsed in 1974, once Chinese and South Korean fleet reached its overwintering grounds (Xu and Liu, 2007), rendering it commercially extinct (Zhao et al., 2002). Although protection measures for the spawning grounds of large yellow croaker were put in place by China in the early 1980s, the stock was severely depleted, and does not seem able to recover (Liu and Sadovy de Mitcheson, 2008).

Another important commercial species of China, yellow croaker (*L. polyactis*), showed first signs of overexploitation in the 1960s, but they were masked by the offshore expansion of the fisheries (Liang and Pauly, 2017a) and large catches of other species (Fei, 1980). The catch of yellow croaker initially decreased, but later appeared to increase to more than two times than that in the 1950s. This stock recovery was the result of China's and South Korea's protective measures, notably a 6-year total ban on fishing in its main spawning ground in the southern Yellow Sea in the 1980s (Lee and Midani, 2014; Yan et al., 2014). However, the recovery of yellow croaker came at a cost, as the adult individuals became much smaller, and reached maturity at

smaller sizes (Dieckmann et al., 2005; Yan et al., 2014), as can be expected on theoretical grounds (Pauly, 1984, 2019).

Japanese anchovy (*E. japonicus*), which had one of three populations found not to be overfished, is a very common and important small pelagic fish, especially as food for other commercial species. As a low-value species (Yu and Zheng, 2000), it was largely a bycatch species until the mid-1980s, when it became the target species of reduction (i.e., fishmeal) fisheries (Zhu et al., 1990; Tang et al., 2002) and thus began to show up in China fisheries statistics and fisheries research. While this research showed that Japanese anchovy was overfished around 2006 (Li et al., 2015), its stock seems to have recovered since, possibly because the top predators in China's coastal seas have been fished out, which reduced predation pressure on small pelagic fish.

Japanese flounder (*Paralichthys olivaceus*), another stock that is currently in good shape, was depleted in the early 1990s. Then, management measures, which include restocking (via the release of juveniles) were put in place and strengthened, which allowed the population to recover (Zhou, 2011).

Osbeck's grenadier anchovy (*C. mystus*), is the only stock found to be recovering. This anchovy is an amphidromous species that is very popular with consumers along the Yangtze River; in fact, it was one of the most important resource species of the Yangtze Estuary before the 1960s (Wang and Ni, 1984; Zheng, 2012). It became even more valuable in the last 30 years, as the

populations of associated species, such as Reeves shad (*Tenuulosa reevesii*) and the noodlefish (*Salanx prognathus*) strongly declined (Ni, 1999). The environment of *C. mystus* is very vulnerable to human activities and terrigenous pollution. Thus, we laud the decision to prohibit the harvesting of Osbeck's grenadier anchovy in the Yangtze River and its estuary, as published on February 1, 2019 (Anon, 2019), and the 10 years' fishing ban for the entire Yangtze River Basin that began in January 2020. These decisions, if vigorously implemented, may help the stock to recover, in spite of the pollution and degradation of its habitat (Yang et al., 2012). Note, finally that the stock of *C. mystus* in the Min River Estuary was found to be in good shape (Zhang et al., 2020), thus suggesting a strong influence of local conditions.

Pacific sardine (*S. sagax*), also known as "South American pilchard" (see text footnote 1; Froese and Pauly, 2019), ranges across the entire Pacific and beyond, and has supported many huge fisheries, notably off Chile and Peru, California (Steinbeck, 1945; Cisneros-Mata et al., 1995; Yáñez et al., 2001), and Japan (Watanabe et al., 1995). The stocks of Pacific sardine fluctuate strongly in response to climatic events, often in similar ways across very distant regions (Lluch-Belda et al., 1989, 1992; Deyle et al., 2013), which led to high catches in China in the 1970s and 1980s (Wang, 1985). As the 2-parameter CMSY model cannot readily accommodate massive changes in biomass due to environmental fluctuations, Pacific sardine treated as if it was overfished in 1950–1975. This allowed its biomass to increase until the 1980s (as occurred in reality), then to decline due to strong fishing pressure and the fading of the environmental conditions that had generated the massive increase. However, we did not report on it "MSY" or other statistics, which would be unrealistic.

CONCLUSION

In conclusion, most stocks we studied have biomasses that are much lower than B_{MSY} , i.e., the biomass associated with MSY. Thus, China loses millions of tonnes every year of potential catch to overfishing, and huge sums in the form of subsidies to fisheries that exploit overfished coastal stocks (Mallory, 2016). Although mariculture and the release of juveniles are maintaining several stocks, this is not a sustainable proposition; also, these measures lead to genetic diversity losses (Wang et al., 2012). Aquaculture should not be expected to maintain wild fish populations. Prudent fisheries management, on the other hand, can do this, and counter fisheries resources degradation. China has now taken

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measures to control its excessive fishing effort and we hope that the present study will serve as supporting scientific evidence toward fishing effort reduction.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

LZ was responsible for data collection, formal analysis, and writing original draft. CL was responsible for data curation, reviewing, and editing the manuscript. DP was responsible for conceptualization, methodology, and supervision. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer DD declared a past co-authorship with one of the authors, DP, to the handling editor.

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