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Sustainable fisheries in shallow lakes: an independent empirical test of the Chinese mitten crab yield model*

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Abstract Next to excessive nutrient loading, intensive aquaculture is one of the major anthropogenic impacts threatening lake ecosystems. In China, particularly in the shallow lakes of mid-lower Changjiang (Yangtze) River, continuous overstocking of the Chinese mitten crab (*Eriocheir sinensis*) could deteriorate water quality and exhaust natural resources. A series of crab yield models and a general optimum-stocking rate model have been established, which seek to benefit both crab culture and the environment. In this research, independent investigations were carried out to evaluate the crab yield models and modify the optimum-stocking model. Low percentage errors (average 47%, median 36%) between observed and calculated crab yields were obtained. Specific values were defined for adult crab body mass (135 g/ind.) and recapture rate (18% and 30% in lakes with submerged macrophyte biomass above and below 1 000 g/m^2) to modify the optimum-stocking model. Analysis based on the modified optimum-stocking model indicated that the actual stocking rates in most lakes were much higher than the calculated optimum-stocking rates. This implies that, for most lakes, the current stocking rates should be greatly reduced to maintain healthy lake ecosystems.

Keyword: Chinese mitten crab; sustainable fishery; yield model; optimum-stocking model; independent test; Changjiang lakes

1 INTRODUCTION

Intensive aquaculture is becoming an important stressor threatening lake ecosystem health. In China, industrial Chinese mitten crab (*Eriocheir sinensis*) culture is an intensive fishery widely practiced in shallow lakes. Although this crab is an invasive species in Europe and America, causing great ecological and economic loss (Rudnick et al., 2003; Dittel and Epifanio, 2009) through damaging dykes and other installations, it has long been a delicacy in China. Crab culturing has a long history in China. In the 1990s, farming of this crab developed rapidly, particularly in the mid-lower Changjiang Basin. This species is now cultured in all of the Chinese inland provinces, cities, and autonomous regions, except for Tibet. Chinese mitten crab is becoming an important component of the freshwater aquaculture industry in China. The total yield in 2011 was 64.9×10^4 tons, corresponding to a value of 45.2×10^{8}US$ (FAO, 2013), accounting for approximately 2% of total production and 10% of the value of Chinese inland aquaculture in that year.

However, rapid crab culture development comes at a cost, bringing ecosystem health deterioration in shallow lakes. For example, high crab densities negatively affect macrophytes as demonstrated by both mesocosm experiments (Jin et al., 2001) and a presence-absence study in a lake (Xu et al., 2003). The negative effects tend to increase with increasing crab stocking density, as suggested by a study in rice and crab culturing systems (Li et al., 2007). In our

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recent large-scale analysis with a combination of long-term (12 years) monitoring in a lake and multi-lake comparisons (20 sub-areas in four lakes), high crab densities led to a decrease in submerged macrophytes and transparency, and, hence, weakened macrophyte-transparency positive feedback, the basic mechanism that maintains the clear-water state in shallow lakes (Wang et al., 2016). In the mid-lower Changjiang Basin, where crab culture has been practiced for decades, many shallow lakes have experienced a regime shift from macrophyte- to phytoplankton-dominated states (Wang et al., 2014). Besides excessive nutrient loading, continuous intensive crab stocking may play an important role. Loss of macrophytes may in turn negatively influence crab culture development because macrophytes are important for crab growth.

A series of maximal crab yield (CY_{Max}) and general optimum-stocking rate (SR_{Opt}) models with a combination of adult crab body mass (BW) and recapture rates (RR, calculated as a ratio of the amount of stocked crabs to the amount of harvested crabs) have been established based on a 1-year investigation of 20 sub-areas in four lakes. The aim was to determine the reasonable natural resource consumption levels for sustainable crab culture (Wang et al., 2006; see also Section 1.1). A test of the yield models based on an independent investigation is needed to evaluate the performance of these models because BW and RR used in the optimum-stocking model were roughly estimated in Wang et al. (2006). A modification of the optimum-stocking model with a more reasonable estimation of BW and RR is also needed.

The purpose of the present research is twofold: 1) to test the predictive ability of the crab yield models developed by Wang et al. (2006) using an independent dataset; and 2) to modify the optimum-stocking model by exploring the key factors affecting adult crab body mass and recapture rates.

1.1 Background of the crab yield models tested

The crab yield models established by Wang et al. (2006) were based on a 12-month investigation during Dec. 2001–Dec. 2002 in 20 crab culture sub-areas in four lakes in the middle Changjiang Basin. The ratio of Secchi depth to water depth (Z_{SD}/Z_M) was used as the independent variable in these models because these two parameters are easy to measure and closely related to submerged macrophytes, which are important for crab growth. Z_{SD}/Z_M during crab stocking season (Dec.–May) was used instead of the annual mean Z_{SD}/Z_M to establish the models (Wang et al., 2006). The model based on the Z_{SD}/Z_M for those four months gave the strongest correlation between Z_{SD}/Z_M and crab yield (CY, calculated as the weight of caught adult crabs divided by area, kg/ha). However, in this study we tested the models (P<0.001) over a time scale of 1 month, because this requires less effort and hence is more practical for local farmers.

Dec.–Jan.: $CY=-21.37+81.16\ Z_{SD}/Z_M,\ R^2=0.61,$ (1)

Mar.: $CY=-1.22+63.9\ Z_{SD}/Z_M,\ R^2=0.49,$ (2)

Apr.: $CY=-7.5+94.56\ Z_{SD}/Z_M,\ R^2=0.64,$ (3)

May: $CY=-24.58+104.31\ Z_{SD}/Z_M,\ R^2=0.70,$ (4)

Because crab stocking has led to serious deterioration in these lakes, the above models were regarded as maximal yield (CY_{Max}) models. According to the MSY (Maximum Sustainable Yield) theory (Larkin, 1977), 50% of the maximal yield was assumed as the maximal sustainable yield, a level that achieves both optimum profit for farmers and environmental sustainability. Accordingly, the optimum-stocking rates (SR_{Opt}, ind./ha) with a combination of adult crab body size (BW) and recapture rate (RR) were estimated as follows:

$$SR_{Opt}=(1000CY_{Max}\times 50\%)/(BW\times RR). \quad (5)$$

2 MATERIAL AND METHOD

2.1 Study sites and sampling

During 2003–2005, 26 lakes (sub-areas) in the mid-lower Changjiang Basin (114°08′–116°53′E, 30°07′–42′N) were investigated from Feb. to May (juvenile crab stocking season) (Table 1). The number of sampling sites in each lake ranged from 3 to 16, depending on lake size. Submerged macrophyte biomass (B_{Mac}), water depth (Z_M), and Secchi depth (Z_{SD}) were measured during the investigation. Z_M and Z_{SD} were measured by a sounding lead and a Secchi Disc, respectively. In terms of submerged macrophytes, 2–4 replicates were sampled by a scythe-type sampler at each sampling site, mixed, cleaned, drained, and then weighed for wet biomass. The adult crab sizes were measured for all of the lakes during the harvest season (autumn, Sep.–Nov.). For each lake, at least 20 crabs were randomly selected from the harvest obtained by the local fish farms. Body mass (weight) was measured with an electronic balance. Because this species of crab is a valuable product, the local farms take detailed notes during the culture process. Therefore, we obtained the stocking and harvest data directly from the local farm's records

Table 1 Stocked Chinese mitten crab populations and main environmental variables in the lakes investigated during 2003–2005

Lake (location)	Sub-area (number of sampling sites)	Area (ha)	Month	SR (ind./ha)	BW (g/ind.)	RR (%)	CY_O (kg/ha)	CY_P (kg/ha)	Z_M (m)	Z_{SD} (m)	Z_{SD}/Z_M	B_{Mac} (g/m^2)	SR_{Opt} (ind./ha)
Lake Bao'anhu (Daye, Hubei Province)	Bao'ankou (4)	363	2003.02	1 791	140	22	55	15	2.10	0.95	0.45	1 592	175
			2004.02	1 157	140	34	55	19	1.51	0.73	0.50	89	395
			2005.04	1 460	180	18	48	45	1.80	1.00	0.56	3	934
	Huangfengkou (3)	188	2003.02	2 340	150	38	133	91	1.45	2.00	1.39	3 779	1 057
			2005.04	2 872	180	22	114	108	1.65	2.00	1.22	216	2 217
	Yexizui (3)	440	2003.02	2 227	140	18	57	40	2.53	1.90	0.75	392	812
			2005.02	1 818	180	17	57	56	2.09	1.98	0.95	313	1 146
	Changlingzhou (3)	440	2003.02	2 864	125	11	40	40	2.53	1.90	0.75	350	812
			2005.04	2 136	180	18	68	82	2.09	1.98	0.95	313	1 692
	Zhuzhou I (3)	323	2003.02	2 415	125	23	70	42	2.30	1.80	0.78	0	862
			2005.04	2 861	140	16	62	88	1.93	1.95	1.01	0	1 809
	Zhuzhou II (3)	323	2003.02	2 254	125	8	23	42	2.30	1.80	0.78	0	862
			2005.04	2 415	125	10	31	88	1.93	1.95	1.01	0	1 809
	Longwangtou I (3)	313	2003.02	1 917	125	13	32	46	2.40	2.00	0.83	579	945
			2005.04	2 300	140	12	40	88	1.93	1.95	1.01	0	1 809
	Longwangtou II (3)	313	2003.02	2 147	125	12	32	36	2.55	1.80	0.70	283	729
			2005.04	1 917	125	13	32	89	2.25	2.30	1.02	889	1 828
	Lianhuazhou (3)	157	2003.02	2 229	130	9	26	47	2.50	2.10	0.84	0	962
	Outang (3)	145	2003.05	2 414	150	17	62	73	2.35	2.20	0.94	0	1 510
	Shuimiao (4)	157	2003.02	3 185	93	31	92	60	2.30	2.30	1.00	5 594	691
			2004.02	1 911	120	26	61	55	1.50	1.40	0.94	846	1 129
			2005.04	2 229	100	36	80	94	2.15	2.30	1.08	9 900	1 945
	Changlingtou (4)	149	2003.02	3 356	93	31	97	60	2.10	2.10	1.00	6 250	691
			2004.02	2 013	120	26	64	32	1.83	1.20	0.66	0	662
			2005.04	2 349	100	36	84	90	1.65	1.70	1.03	2 243	1 039
	Tongshawan (3)	191	2003.02	1 832	150	19	52	41	2.20	1.70	0.77	0	845
	Biandantang (6)	333	2003.05	2 102	113	18	44	36	2.00	1.17	0.58	0	738
			2005.04	2 631	138	17	60	34	1.86	0.82	0.44	0	701
Niushan Lake (Wuhan, Hubei Province)	Eastern (6)	1 750	2003.02	1 664	130	24	53	67	3.60	3.90	1.09	862	1 379
	Middle (6)	1 175	2003.02	1 664	130	16	34	75	3.43	4.00	1.19	0	1 546
	Western (6)	1 333	2003.02	1 664	130	15	32	50	3.30	2.90	0.88	11	1 029
Niushan Lake	(18)	4 258	2005.03	1 353	150	35	71	60	2.53	2.39	0.95	8 900	688
Luhu Lake (Wuhan, Hubei Province)	Wuqianmu (3)	571	2005.03	963	150	15	22	54	1.35	1.18	0.87	2 061	629
	Yiwanwu (6)	1 210	2005.03	1 488	140	44	91	48	1.48	1.13	0.77	1 623	555
Liangzi Lake	Western (16) (Wuhan, Hubei Province)	6 667	2003.02	1 387	147	22	45	28	3.64	2.22	0.61	359	578
			2005.03	2 246	140	14	44	61	2.11	2.06	0.98	61	1 262
Ninggang Lake	(Wuhan, Hubei Province) (4)	1 000	2005.03	1 448	160	39	90	68	1.93	2.10	1.09	378	1 407
Zhangdu Lake	(Wuhan, Hubei Province) (9)	3 520	2004.02	938	110	23	23	63	1.25	1.30	1.04	0	1 296
Qihu Lake (Wuhan, Hubei Province)	Upper (2)	133	2004.02	1 504	125	20	38	60	0.70	0.70	1.00	0	1 229
			2005.03	3 008	100	18	55	50	0.85	0.68	0.80	0	1 026
Huama Lake	Middle (E'Zhou, Hubei Province) (6)	307	2004.04	1 467	140	10	21	72	0.81	0.65	0.84	96	1 479
			2005.03	2 282	140	7	21	41	2.13	1.40	0.66	64	842
Wuchang Lake	Upper (Wangjiang, Anhui Province) (8)	4 713	2005.04	849	165	23	32	46	1.29	0.72	0.56	0	934

SR: crab stocking rate; BW: adult crab body mass; RR: adult crab recapture rate (CY_O×1 000/BW)/SR×100; Z_M: mean depth; Z_{SD}: Secchi depth; B_{Mac}: submerged macrophyte biomass; CY_O: observed crab yield; CY_P: crab yield calculated from Models 1, 2, 3, and 4, corresponding to Feb., Mar., Apr., and May, respectively; SR_{Opt}: optimum-stocking rate calculated from Models 6–9 when B_{Mac}<1 000 g/m^2 and Models 10–13 when B_{Mac}>1 000 g/m^2; Models 6 and 10 were used for Feb., Models 7 and 11 for Mar., Models 8 and 12 for Apr., and Models 9 and 13 for May.

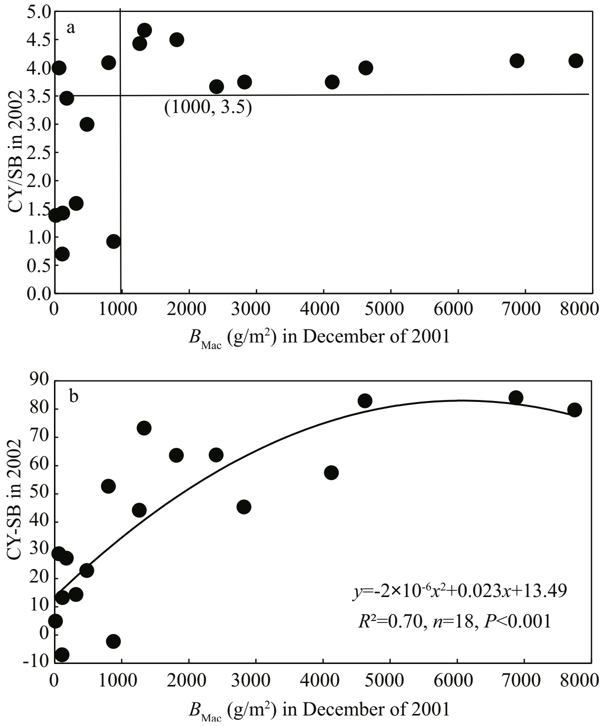

Fig.1 Relationship between submerged macrophyte biomass (B_{Mac}) in 2001 and the ratio and difference between initial biomass (SB, kg/ha) and end biomass (reflected by crab yield, CY, kg/ha) in 2002

for all lakes in all years.

The dominant submerged macrophytes in these lakes were *Potamogeton crispus*, *P. maackianus*, *Vallisneria* spp., *Hydrilla verticillata*, *Ceratophyllum oryzetorum*, and *Myriophyllum spicatum*.

2.2 Data analysis

The 2003–2005 data given in Table 1 were used to test the crab yield models established by Wang et al. (2006). When calculating the predicted crab yield (CY_P), Z_{SD}/Z_M measured in Feb. was entered into Model 1 and those measured in Mar., Apr. and May were entered into Models 2, 3, and 4, respectively. A percentage error (PE) was calculated for each case as the difference between observed (CY_O) and predicted (CY_P) crab yield, $|CY_P/CY_O-1|\times100$.

To modify the optimum-stocking model by Wang et al. (2006), a Spearman's rank correlation was used to explore the most important factors affecting adult crab body mass (BW) and recapture rate (RR). Culture practice and lake conditions are considered potentially important factors. They are crab juvenile (SR) stocking rate representing crab culture intensity, area and Z_M representing lake dimensions, Z_{SD} and Z_{SD}/Z_M representing water quality, and B_{Mac} representing food resources and information on water quality.

To compare the harvested biomass (i.e., CY) with the initial (i.e., stocked) biomass (SB), their ratio (CY/SB) and difference (CY-SB) were calculated. SB was calculated by multiplying SR by 10 g, an averaged weight of stocked juveniles (Wang et al., 2006).

Microsoft Excel® 2010 and STATISTICA 8.0 were used for data processing and analysis.

3 RESULT

3.1 Relationship between net harvest and submerged macrophytes

When submerged macrophyte biomass (B_{Mac}) in 2001 was higher than 1 000 g/m², the ratios of initial biomass (SB) and end biomass (reflected by crab yield, CY) in 2002 were >3.5 and average=4.1 (between 3.8 and 4.7), respectively (Fig.1). When B_{Mac}<1 000 g/m², the ratio was 2.3 on average (between 0.7 and 4.1) and five of the nine lakes had a ratio around one. A highly significant positive relationship was found between B_{Mac} in 2001 and CY-SB in 2002. CY-SB was much higher in lakes with B_{Mac}>1 000 g/m² (average=66 and ranging from 44–84) than in lakes with B_{Mac}<1 000 g/m² (average=17 and ranging from -7–53).

3.2 Predictive ability of the established crab yield models

The percentage predicted errors (PEs) of the four crab yield models (Models 1–4) were analyzed based on the difference between observed (CY_O) and predicted (CY_P) crab yields (Table 1). Although a large variation was observed in PE (0.2%–259.0%), the mean (47%) and median (36%) values were relatively low (Fig.2).

When comparing the predicted errors among the four models, Model 1 corresponding to Feb. had the highest mean value (57.2%), followed by Model 2 of Mar. (40.8%), Model 3 of Apr. (37.0%), and Model 4 of May (17.6%). When analyzing the PE Spearman's rank correlations of the potential affecting factors (SR, area, Z_M, Z_{SD}, Z_{SD}/Z_M, and B_{Mac}), no significant correlation was found (P=0.21–0.59) (Table 2).

3.3 Factors affecting adult crab harvest

Adult crab body mass (BW) was only significantly correlated with juvenile crab stocking rates (SRs) and lake surface area (area) (Table 2). However, variations from the fitted lines in the scatterplots were quite

Table 2 Spearman's rank correlations of percentage errors in the crab yield models (PE), adult crab body mass (BW) and recapture rate (RR) with crab stocking rate (SR), lake area (area), water depth (Z_M), Secchi depth (Z_{SD}), ratio of Secchi depth to water depth (Z_{SD}/Z_M), and submerged macrophyte biomass (B_{Mac})

n=43		SR (ind./ha)	Area (ha)	Z_M (m)	Z_{SD} (m)	Z_{SD}/Z_M	B_{Mac} (g/m²)
PE (%)	*R*	-0.18	0.10	-0.12	-0.18	-0.20	-0.08
	P	0.24	0.52	0.44	0.24	0.21	0.59
BW (g/ind.)	*R*	**-0.37**	**0.43**	-0.06	0.01	-0.09	-0.02
	P	**0.02**	**0.004**	0.72	0.96	0.55	0.91
RR (%)	*R*	-0.19	-0.01	-0.25	0.02	0.18	**0.44**
	P	0.22	0.96	0.10	0.90	0.25	**0.003**

Significance correlation at $P<0.05$ was shown in bold.

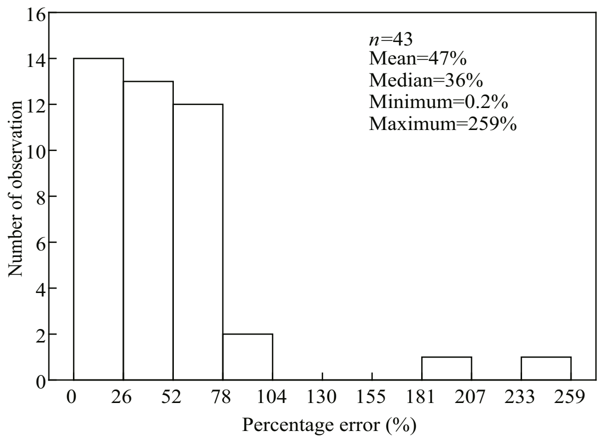

Fig.2 Distribution of the percentage errors in the crab yield models established by Wang et al. (2006) tested with the independent dataset given in Table 1

large for the BW with SR and area regressions (Fig.3a, b).

Similarly, adult crab recapture rate (RR) was only significantly correlated with submerged macrophyte biomass (B_{Mac}) (Table 2). The variations from the fitted line in the plots were also quite large (Fig.3c). Further analysis revealed that RR in the lake groups with B_{Mac}<10 g/m², 10–100 g/m², and from 100–1 000 g/m² (average 17%, 16%, and 20%, respectively) did not differ significantly from each other ($P\geq0.86$) (Fig.4). RR in the lake group with B_{Mac}>1 000 g/m² (averaged 32%), however, was significantly higher than all of the other three groups (average 18%) ($P<0.006$).

3.4 Optimum-stocking model modification

Because no close relationship was found between adult crab body mass (BW) and the potential affecting factors, the average value of 135 g/ind. was defined for BW to be included in the optimum-stocking model. For the crab recapture rates (RRs), two specific values were defined. They were 18% for lakes with

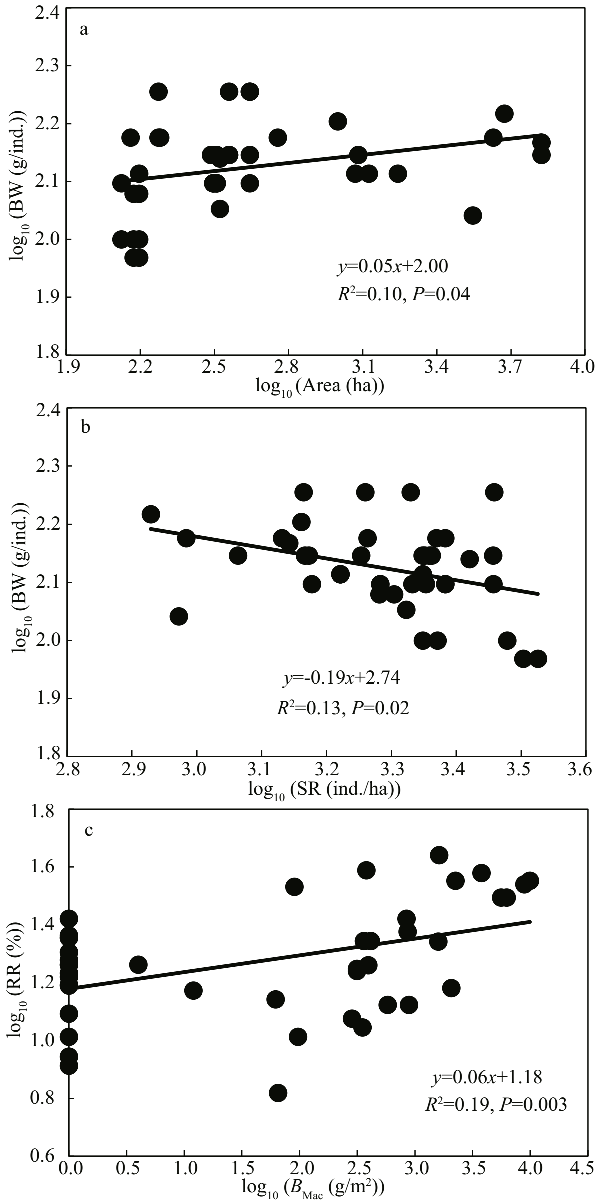

Fig.3 Relationship between adult crab body mass (BW) and lake surface area (area) (a) and juvenile crab stocking rate (SR) (b) and between adult crab recapture rate (RR) and submerged macrophyte biomass (B_{Mac}) (c) (n=43)

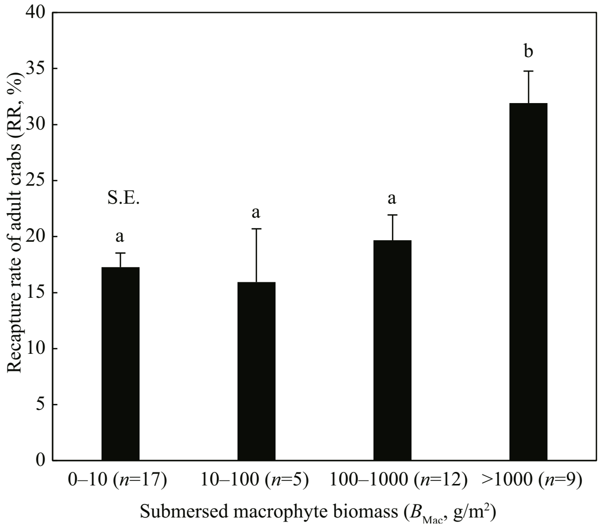

Fig.4 Adult crab recapture rate in lakes with submerged macrophyte biomass <10 g/m², 10–100 g/m², 100–1 000 g/m², and >1 000 g/m²

B_{Mac}<1 000 g/m^2 and 32% for lakes with B_{Mac}>1 000 g/m^2. Therefore, when Models 1–4 were included, the Model 5 optimum-stocking rates (SR_{Opt}) for lakes with B_{Mac}<1 000 g/m^2 were further defined as:

Feb.: SR_{Opt}=-439.3+1668.3 Z_{SD}/Z_M, (6)

Mar.: SR_{Opt}=-25.1+1313.5 Z_{SD}/Z_M, (7)

Apr.: SR_{Opt}=-154.2+1943.7 Z_{SD}/Z_M, (8)

May: SR_{Opt}=-505.3+2144.2 Z_{SD}/Z_M, (9)

for lakes with B_{Mac}>1 000 g/m^2 as:

Feb.: SR_{Opt}=-247.1+938.4 Z_{SD}/Z_M, (10)

Mar.: SR_{Opt}=-14.1+738.8 Z_{SD}/Z_M, (11)

Apr.: SR_{Opt}=-86.7+1093.4 Z_{SD}/Z_M, (12)

May: SR_{Opt}=-284.2+1206.1 Z_{SD}/Z_M, (13)

4 DISCUSSION

4.1 Reliance of crab culture sustainability on macrophytes

In this study, a highly significant positive relationship was found between crab biomass accumulation and macrophyte biomass at the time of crab stocking (Fig.1). This demonstrates the importance of macrophytes in supporting crab culture, especially when macrophyte biomass is >1 000 g/m^2. Submerged macrophytes may benefit crabs by providing food either directly or indirectly (Dvorăk and Bestz, 1982; Ju and Shu, 1999; Jin et al., 2003) and providing appropriate habitats to avoid predators, particularly during molting (Pan, 2002). Our results also suggest that these are the dominant mechanisms based on the significantly higher recapture rate in lakes with abundant macrophytes (Fig.4).

Furthermore, the lower, even negative crab biomass accumulation in lakes with B_{Mac}<1 000 g/m^2 further demonstrates that fewer macrophytes could not support sustainable crab culture. The negative impacts of crabs on macrophytes have been widely reported in studies of various scales (Jin et al., 2001; Xu et al., 2003; Li et al., 2007; Wang et al., 2016), implying that continuous high-density crab stocking may in turn prevent sustainable crab culture. Low macrophyte density is also weak in its resilience to crab disturbance. Therefore, reasonable crab stocking rates and sufficient macrophyte abundance are the two fundamental factors for both sustainable crab culture and healthy ecosystems.

4.2 Yield model test and optimum-stocking model modification

Average and median percentage errors of 47% and 36%, respectively, were obtained for the crab yield models established by Wang et al. (2006). No comparable result can be found in the literature because no similar prior research has been carried out. Out of approximately 150 biogeochemical models, Arhonditsis and Brett (2004) obtained a median percentage error of 44% for phytoplankton, 70% for zooplankton, and 36% for bacteria. A much higher percentage error was obtained by phytoplankton chlorophyll *a* models, e.g., 95% (Canfield Jr, 1983) and 92% (Wang et al., 2008).

In Wang et al. (2006), BW was preliminarily suggested as 150 g/ind. However, such a value is not ideal for these lakes because BW (75%) was <150 g/ind. in most cases. In this study, no close relationship was found between BW and the other factors. BW was only slightly significantly related to lake surface area and stocking rate. It is, therefore, impossible to define specific BW classes relating to either different culture practices or lake conditions. The fact that BW only varied slightly might explain the poor relationships. The BW coefficient of variation among these lakes was as low as 16%. It is safe, however, to set the mean as the specific value for BW because of its small variation.

Wang et al. (2006) proposed that RR=30%, a value calculated from lakes with abundant macrophytes and zoobenthos. However, only 20% of the lakes in this study approached an RR of 30%. In this study, no reliable relationship was found to define RR. However, RR can be defined specifically for lake

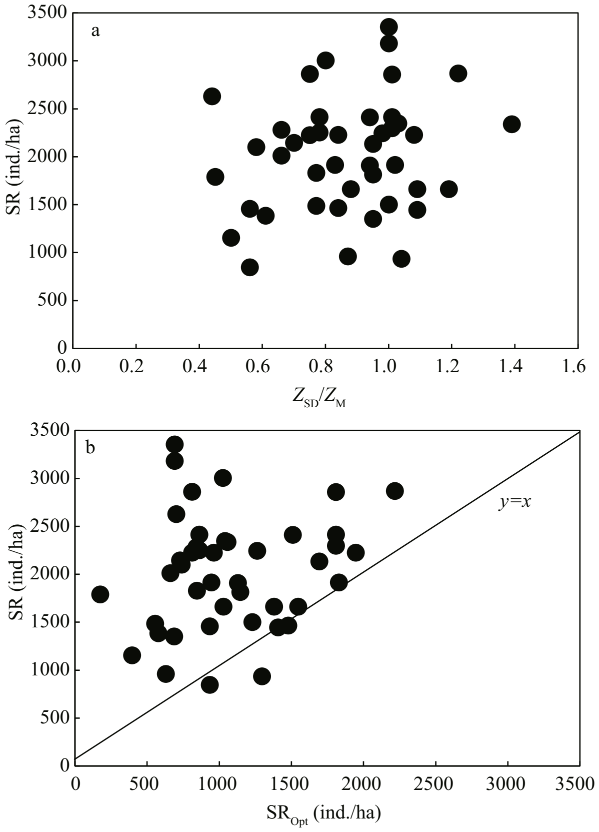

Fig.5 The relationships between the actual stocking rates (SRs) and the ratio of Secchi depth to mean depth (Z_{SD}/Z_M) (a) and the calculated optimum-stocking rates (SR_{Opt}) (b) (*n*=43)

groups with B_{Mac} less and greater than 1 000 g/m^2 because of their significantly different RRs (Fig.4). The significantly higher RR in lakes with B_{Mac}>1 000 g/m^2 is mainly because macrophytes provide an ideal habitat for the crabs. The crabs may hide among macrophytes to avoid either predators or attacks from other crabs. They may also forage for food among the macrophytes.

4.3 Application of the optimum-stocking models

The actual stocking rate and Z_{SD}/Z_M (Fig.5a) scatterplots revealed that the fishermen did not consider lake conditions when stocking crab seed. The stocking intensities were similar in lakes with different Z_{SD}/Z_M values. When using the newly defined Models 6–13 to calculate the optimum-stocking rates in these lakes, the actual stocking rates were much higher than the calculated rates in 86% of cases (37 of 43) (Fig.5b). Therefore, current stocking rates should be greatly reduced in most of the lakes. An alternative strategy to maintain healthy lake ecosystems is a rotation of crab stocking. One option is to separate the lake into two parts and rotate every 2 or 3 years, only stocking one section in any given year. Another option is to stock mitten crabs every 2 or 3 years.

5 CONCLUSION

We evaluated the crab yield models established by Wang et al. (2006) by an independent dataset. These models performed well, obtaining an average and median percentage error of 47% and 36%, respectively. The optimum-stocking model by Wang et al. (2006) was modified by defining specific values for adult crab body mass (BW) and recapture rate (RR) to be included in the model. BW was defined as 135 g/ind. and RR was defined as 18% for lakes with B_{Mac}<1 000 g/m^2 and 30% for lakes with B_{Mac}>1 000 g/m^2.

When using the modified models to calculate the optimum-stocking rates in these lakes, the actual stocking rates were much higher than the calculated rates in most cases. Therefore, we suggest a reasonable approach to crab culture based on our results to maintain healthy lake ecosystems and sustain profit. In lakes with low underwater light conditions, poor food resources and submerged vegetation, crab stocking rates should be massively reduced and possibly even ceased.

6 ACKNOWLEDGEMENT

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