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Performance and Prospect of Freshwater Fisheries Carbon Sink in China

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ABSTRACT

Background: Freshwater fisheries carbon sink generally refer to such fishery production activities that can facilitate biological absorption of CO_2 in the freshwater and therefore remove carbon through harvesting aquatic fishery resources.

Methods: For the amount of carbon sink from freshwater aquaculture products, it is only estimated from the natural feed portion, while the carbon in freshwater fishery products comes from natural food, so the average carbon content is used to estimate the amount of carbon sink.

Result: The annual carbon sink from freshwater aquaculture products in China were 1.714, 1.593, 1.621, 1.673, 1.717, 1.763, 1.809, 1.863 and 1.919 million tons from 2015 to 2023, respectively, with an average of 1.741 million tons. The annual carbon sink capacities for freshwater fishery products in China were 0.295, 0.258, 0.283, 0.256, 0.240, 0.190, 0.157, 0.153 and 0.153 million tons from 2015 to 2023, respectively, with an average of 0.221 million tons.

Key words: Ecological fisheries, Freshwater fisheries carbon sink, Performance and prospect, “Ten-year fishing ban”.

INTRODUCTION

Climate warming has been a world-concerned global problem. Fixing and sequestrating greenhouse gases by biological carbon sink is one of the most economical and effective ways. Freshwater fishes and aquaculture could remove carbon from freshwater, but also provide food for the human beings. Freshwater products are rich in nutrients and are an important source of dietary nutrition for the human body. It is necessary to give ecological compensation to promote carbon-sink fishery better serve the carbon neutrality goal (Zheng *et al.,* 2022). Lakes have a disproportionate effect on the global carbon (C) cycle relative to their area, mediating C transfer from land to atmosphere, and burying organic-C in their sediments. Global lake C-sequestration (~0.12 Pg $year^{-1}$) has increased by ~72 Tg $year^{-1}$ since 1900, offsetting 20% of annual CO_2 freshwater emissions rising to ~30% if reservoirs are included and contributing to the residual continental C sink. Nutrient availability explains ~70% of the observed increase, while rising temperatures have a minimal effect (Anderson *et al.,* 2022). Freshwater aquaculture is an important agricultural product production method in China, and achieving better development is essential to ensure the supply of freshwater products and meet people’s daily needs. Freshwater capture fisheries is an important part of the carbon sinks fisheries, academic discussion on the evaluation method of carbon sinks in freshwater capture fisheries is an important content.But with the decline of aquatic resources, the catch of aquatic products is reducedÿthe development of the carbon sink capacity for freshwater aquaculture will increase in importance. For example, by filtering plankton, filter-feeding fish can reduce indirectly atmospheric carbon dioxide concentration and exert carbon sink function.

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The paper presented carbon sink from freshwater aquaculture and fishery products. Then, freshwater fisheries carbon sink are evaluated based on 2015 to 2023 relevant statistics of Chinese aquaculture. At last, It is further discussed that the large-water ecological fishery and rice-fish integrated culture provide infinite possibility and broad space for the development of carbon sink in freshwater fisheries. Strengthen the protection of rare and endangered species, carry out important habitat restoration, strengthen the investigation and monitoring of resources, and strengthen the prevention and control of exotic species, accelerating ecological restoration is the key to the combination of carbon sink in freshwater fisheries and the “Ten-year fishing ban” strategy of the Yangtze River. The research will make a good preparation for development of freshwater fisheries carbon sink under the carbon neutrality target and impel the scientific and healthy development of modern fisheries.

MATERIALS AND METHODS

The freshwater aquaculture yield and fishing yield are derived from the Chinese fishery statistical yearbook, 2016-2024, which has been published for eight consecutive years.

The carbon of fishing fish comes from natural food, so the carbon sink is estimated by its average carbon content. In cultured fish, silver carp and bighead carp are filter feeders, which feed mainly on plankton. It can be considered that their carbon comes from natural food. Suppose that 20% of the yield of grass carp, crucian carp, carp and so on comes from natural feed, while 50% of the yield of river crab comes from natural feed (Xie *et al*. , 2013).

RESULTS AND DISCUSSION

The annual carbon sink

From 2015 to 2023, except for 2016, the annual carbon sink from freshwater aquaculture products in China increased steadily year by year, to 1.714, 1.593, 1.621, 1.673, 1.717, 1.763, 1.809, 1.863 and 1.919 million tons respectively, an average of 1.741 million tons of carbon are removed each year (Table 1). From 2015 to 2023, except for 2017, The annual carbon sink capacities for freshwater fishery products in China declined year by year, to 0.295, 0.258, 0.283, 0.256, 0.240, 0.190, 0.157, 0.153 and 0.153 million tons respectively, with an average annual carbon sequestration of 0.221 million tons, fish contributed the most, accounting for more than 78% of the total carbon removed from freshwater fishery in China (Table 2) . The 10 provinces with the largest annual carbon sink from freshwater aquaculture products were Hubei, Jiangsu, Anhui, Hunan, Jiangxi, Guangdong, Sichuan, Guangxi, Henan and Shandong, that was 355936, 231779, 190268, 185021, 180100, 134318, 111665, 80447, 63996 and 63842 tons respectively (Table 3). Jiangsu, Zhejiang, Henan, Shandong, Anhui, Guangxi, Guangdong, Fujian, Heilongjiang and Hebei were the 10 provinces with the largest carbon removal from freshwater fishery products , that was 22237, 21304, 14869, 13611, 12850, 10684, 9766, 9231, 7048 and 5712 tons respectively (Table 4).

Ecological fisheries in large water bodies

In 2020, China committed to peak carbon by 2030 and carbon neutrality by 2060, and vigorously developing low-carbon and carbon sequestration technologies appropriate to China's national conditions is the only way to achieve the goals of peak carbon and carbon neutrality. Carbon sink research is necessary to ensure China achieves its goal of carbon neutrality (Lai *et al*, 2022). Fish consumption is increasing worldwide. Our food needs, especially fish, will be 70% higher (Guetarni and Labdi, 2023). Fish is a vital part of the regular diet and a cheap source of protein for the peoples (Sit *et al*., 2021). Fisheries that do not require feeding have a carbon sink function and may form biological carbon sinks, which can also be referred to as carbon sink fisheries (Liu *et al*., 2011; Yang *et al*., 2012). From 2010 to 2014, the annual carbon sink from freshwater aquaculture products in China was 1.362, 1.405, 1.460, 1.530, 1.645 million tons respectively, an average of 1.480 million tons of carbon were removed each year (Wu *et al.,* 2016). This study shows, from 2015 to 2023, except for 2016, the annual carbon sink from freshwater aquaculture products in China increased steadily year by year, to 1.714, 1.593, 1.621, 1.673, 1.717, 1.763, 1.809, 1.863 and 1.919 million tons respectively, an average of 1.741 million tons of carbon are removed each year. The contribution of carbon removal from silver carp is the largest, followed by bighead carp. Research by Gao *et al*. (2023) showed that the net enclosure removed 632.07 kg of carbon per hectare in the ecological fishery model of the non-feeding bighead carp-crab fishery model in Dongping Lake. According to the 2024 China Fishery Statistics yearbook, in 2023, the area of fish farming in lakes and reservoirs accounted for 42.44 percent of the country's freshwater farming area, an area of 2483.36 thousand hectares, Assuming all reach carbon sequestration levels similar to the non-feeding bighead carp-crab fishery model in Dongping Lake, the carbon sequestration could reach 1.57 million tons, it is suggested that ecological fisheries in large water bodies have great potential in freshwater carbon sink fisheries.

Rice-fish integrated culture

It should be emphasized that the contribution of carbon removal from shrimp is increasing rapidly year by year, and in 2017, it surpassed that of grass carp, ranking third. In 2023, silver carp, bighead carp and shrimp accounted for 76.6% of the total carbon removed from freshwater aquaculture in China. The extension of rice-crayfish cocropping model in China is one of the main reasons for the increase of carbon removal from shrimp. Rice-fish integrated culture makes full use of the ecological niche within the rice field ecosystem, and makes full use of the nutrients and water resources in the rice field to exert the interaction between rice and aquatic animals, thus effectively reducing the input of agricultural costs (Xie *et al.,* 2011), to achieve "One water, two crops, one field", rice and aquatic products to achieve two-way win-win income generation (Stankus and Halwart, 2017; Wang, 2018; Xiao *et al.,* 2019). Wang (2023) studied the characteristics of rice growth and greenhouse gas emissions in the rice-duck-shrimp model, showing that the carbon sink capacity of the rice-duck-shrimp model increased by 1,005-1,490 kg per hectare compared with that of the rice-duck-shrimp model. According to the 2024 China Fishery Statistics yearbook, in 2023, the area of fish cultivated in the paddy fields was 2,863.71 thousand hectares. Assuming that all the fish reached the carbon sink level of the rice-duck-shrimp model, the amount of carbon removed could reach 3.01 to 4.46 million tons, it is suggested that the study of ecological effect and its mechanism of rice-fish integrated cropping system can effectively enhance its carbon sequestration capacity.

Study reveals that the majority of the farmer's were dependent upon traditional paddy-cum-fish culture (Yani

Table 1: The annual carbon sink from freshwater aquaculture products in China from 2015 to 2023 (excluding feed culture, 10,000 tons).

Species	2015		2016		2017		2018		2019	
	Carbon sink	Proportion	Carbon sink	Proportion	Carbon sink	Proportion	Carbon sink	Proportion	Carbon sink	Proportion
Silver carp	70.5	41.1%	63.4	39.8%	61.7	35.9%	62.5	37.4%	61.7	35.9%
Bighead	45.0	26.3%	41.7	26.2%	41.6	24.2%	41.5	24.8%	41.6	24.2%
Grass carp	14.5	8.5%	13.5	8.5%	14.2	8.3%	14.1	8.4%	14.2	8.3%
Crucian carp	8.3	4.8%	7.8	4.9%	7.8	4.6%	7.9	4.7%	7.8	4.6%
Carp	7.6	4.5%	6.8	4.3%	6.6	3.8%	6.7	4.0%	6.6	3.8%
Parabramis and Megalobrama	2.7	1.6%	2.8	1.8%	2.6	1.5%	2.6	1.6%	2.6	1.5%
Mandarin fish	3.8	2.2%	4.0	2.5%	4.3	2.5%	4.0	2.4%	4.3	2.5%
Shrimp	12.4	7.2%	13.2	8.3%	27.2	15.8%	22.2	13.3%	27.2	15.8%
Mussels	0.9	0.5%	0.8	0.5%	0.5	0.3%	0.5	0.3%	0.5	0.3%
Snail	0.9	0.5%	0.8	0.5%	0.7	0.4%	0.8	0.5%	0.7	0.4%
Freshwater clams	0.3	0.2%	0.2	0.2%	0.2	0.1%	0.2	0.1%	0.2	0.1%
River crab	4.6	2.7%	4.2	2.6%	4.3	2.5%	4.2	2.5%	4.3	2.5%
Total	171.4	1	159.3	1	171.7	1	167.3	1	171.7	1

Species	2020		2021		2022		2023	
	Carbon sink	Proportion	Carbon sink	Proportion	Carbon sink	Proportion	Carbon sink	Proportion
Silver carp	61.7	35.0%	62.1	34.3%	62.8	33.7%	62.5	32.6%
Bighead	41.9	23.8%	42.6	23.5%	43.8	23.5%	44.9	23.4%
Grass carp	14.3	8.1%	14.7	8.2%	15.1	8.1%	15.2	7.9%
Crucian carp	7.8	4.4%	8.1	4.5%	7.9	4.2%	8.1	4.2%
Carp	6.6	3.7%	6.4	3.6%	6.5	3.5%	6.5	3.4%
Parabramis and Megalobrama	2.6	1.5%	2.6	1.4%	2.6	1.4%	2.5	1.3%
Mandarin fish	4.8	2.7%	4.8	2.6%	5.1	2.7%	6.1	3.2%
Shrimp	30.9	17.5%	33.6	18.6%	36.5	19.6%	39.7	20.7%
Mussels	0.5	0.3%	0.5	0.3%	0.5	0.2%	0.5	0.3%
Snail	0.7	0.4%	0.8	0.4%	0.8	0.4%	0.8	0.4%
Freshwater clams	0.2	0.1%	0.2	0.1%	0.2	0.1%	0.2	0.1%
River crab	4.3	2.4%	4.5	2.5%	4.5	2.4%	4.9	2.6%
Total	176.3	1	180.9	1	186.3	1	191.9	1

et al., 2022). Fisheries have integrated biological carbon sequestration strategies that improve their carbon sink function and emphasize the development of a low-carbon economy (Ren, 2021; Zhang *et al.,* 2017). Numerous assessment methods exist to quantify removable carbon sinks, including the material quality assessment method (Hu *et al.,* 2021), remote sensing estimation method (Wang *et al.,* 2018), model simulation method (Mueller et al 2004), *etc*., among which the material quality assessment method is widely used because of its convenience of application and high accuracy (Lai *et al.,* 2022). From 2015 to 2023, except for 2017, The annual carbon sink capacities for freshwater fishery products in China declined year by year, to 0.295, 0.258, 0.283, 0.256, 0.240, 0.190, 0.157, 0.153 and 0.153 million tons respectively, with an average annual carbon sequestration of 0.221 million tons.

The "Ten-year fishing ban" strategy of the Yangtze River

The "Ten-year fishing ban"of the Yangtze River has become an important strategy aiming at ecological protection. In the short term, a total ban on productive fishing will inevitably lead to a precipitous drop in the amount of carbon sink from freshwater fisheries in the relevant waters. But "Yangtze River basin aquatic living resources and habitat status bulletin (2022)" shown, 193 species of fish were recorded in key waters of the Yangtze River in 2022, an increase of 25 species from 2020. The population of the Yangtze finless porpoise was 1,249 in 2022, which realized the historical turn of the rebound. With the recovery of resources and the increase of biomass, the ecosystem carbon sink in the relevant waters of "Ten-year fishing ban" in the Yangtze River basin shows an increasing trend. For example, research by Yang Shufan *et al*. (2023) shows that, the size of Poyang Lake's ecosystem increased by 8.07% and the total biomass increased by 35.7% after the ten-year fishing ban. Based on Hu Zhongyu *et al*. (2024) 's methods for estimating the carbon sink contribution and carbon sink potential of natural forests in China, the biomass conversion factor method can be used to calculate the carbon storage and carbon density of the relevant waters of the Yangtze river basin during the "Ten-year fishing ban", the carbon sink potential was predicted by Logistic growth equation. At the same time, in view of the rapid recovery of some fish resources in relatively closed waters such as some lakes and reservoirs where fishing is prohibited, ecological fishing and large-scale aquaculture demonstrations have been carried out, the intensity and sustainability of carbon removal from freshwater fisheries can be assured. The "Ten-year fishing ban" on the Yangtze River is conducive to the sustainable development of carbon sink fisheries, including strengthening the protection of rare and endangered species, carrying out important habitat restoration, strengthening the investigation and monitoring of resources, and strengthening the prevention and control of alien species, accelerating ecological restoration is the key to the combination of carbon sink fisheries and the "Ten-year

Table 2: The annual carbon sink from freshwater fishery products in China from 2015 to 2023 (10,000 tons).

Species	2015		2016		2017		2018		2019	
	Carbon sink	Proportion	Carbon sink	Proportion	Carbon sink	Proportion	Carbon sink	Proportion	Carbon sink	Proportion
Fish	23.6	79.8%	20.3	78.6%	22.6	79.9%	20.6	80.6%	19.4	80.7%
Crustaceans	3.4	11.6%	3.2	12.2%	3.2	11.2%	2.8	11.1%	2.6	10.8%
Shellfish	2.5	8.6%	2.4	9.2%	2.5	8.9%	2.1	8.3%	2.0	8.5%
Total	29.5	1	25.8	1	28.3	1	25.6	1	24.0	1
Species	2020		2021		2022		2023			
	Carbon sink	Proportion	Carbon sink	Proportion	Carbon sink	Proportion	Carbon sink	Proportion		
Fish	15.5	81.6%	12.9	82.3%	12.6	82.5%	12.7	83.13%		
Crustaceans	1.8	9.4%	1.4	8.7%	1.4	8.9%	1.3	8.69%		
Shellfish	1.7	9.0%	1.4	9.0%	1.3	8.6%	1.3	8.29%		
Total	19.0	1	15.7	1	15.3	1	15.3	1		

Table 3: The annual carbon sink from freshwater aquaculture products by Chinese provinces in 2023 (excluding feed culture, 10,000 tons).

	Silver carp	Bighead fish	Grass carp	Crucian carp	Carp	Parabramis and Megalobrama	Mandarin fish	Shrimp	Mussels	Snail	Freshwater clams	River crab	Total
Beijing	94.71	29.75	77.63	11.97	87.88	11.98	0.00	0.00	7.12	0.00	0.00	0.00	321.04
Tianjin	3171.14	1223.55	973.36	921.97	1825.35	22.57	6.75	2.22	0.00	0.00	0.00	325.17	8472.07
Hebei	5425.43	2215.02	853.61	572.95	2453.35	1.35	6.11	5.65	0.00	0.00	0.00	235.04	11768.51
Shanxi	1668.06	548.46	416.81	34.61	258.28	0.27	0.51	31.80	7.12	0.00	0.00	8.27	2974.19
Inner Mongolia	2598.17	1929.87	351.66	298.42	861.41	15.72	2.55	15.29	0.00	0.00	0.00	38.30	6111.38
Liaoning	13806.99	7044.11	2738.34	1895.64	7112.75	142.11	46.21	0.00	0.00	0.00	0.00	3885.11	36671.27
Jilin	8504.61	5553.76	544.19	911.47	1227.47	66.74	42.39	20.05	0.27	0.00	0.00	332.06	17203.02
Heilongjiang	22478.52	7973.54	1937.15	3641.32	5666.44	8.27	174.27	38.23	0.00	0.00	0.00	1068.65	42986.38
Shanghai	1188.67	993.34	494.57	268.81	4.93	38.56	4.07	185.59	0.00	0.00	0.00	334.00	3512.55
Jiangsu	76752.74	38106.92	11640.93	16713.99	4247.30	5194.91	4107.46	49257.03	547.71	1852.37	854.72	22503.03	231779.11
Zhejiang	22611.28	14266.18	2459.83	2878.36	822.46	1094.05	1205.66	11451.84	308.39	409.27	19.13	567.32	58093.76
Anhui	42778.03	36498.65	7080.24	5594.94	1976.07	3083.30	6647.35	76829.83	2353.43	1437.39	88.37	5900.87	190268.47
Fujian	13786.92	8931.10	4651.80	1198.21	1316.67	153.15	142.96	750.34	286.67	310.54	894.86	21.92	32445.13
Jiangxi	49578.80	60358.96	17778.05	7759.91	3449.42	2167.86	6156.23	29087.55	765.31	1835.16	375.04	787.55	180099.84
Shandong	26528.77	15265.01	5665.68	2614.09	4887.75	65.93	226.98	7118.57	17.00	4.44	0.00	1447.66	63841.89
Henan	29856.95	18671.43	3825.99	1558.17	3062.97	286.86	38.06	6549.94	22.96	6.66	1.11	114.66	63995.76
Hubei	82913.69	64248.58	21771.11	10323.38	1874.65	7744.81	17083.41	138863.87	212.62	213.87	33.73	10652.23	355935.94
Hunan	54359.71	42848.11	16801.47	6511.51	3689.09	2977.25	4780.50	51695.96	395.61	501.02	11.17	450.11	185021.48
Guangdong	30561.05	43323.00	23875.10	4369.66	1823.94	561.47	19504.78	9901.53	22.25	167.48	12.28	194.97	134317.52
Guangxi	38289.84	25182.62	8854.02	989.23	3706.00	54.39	51.05	2475.27	120.06	691.65	15.71	17.59	80447.42
Hainan	803.19	1290.69	110.04	20.05	47.69	3.51	0.00	168.42	0.00	2.46	0.00	0.00	2446.03
Chongqing	18755.79	8316.17	3862.34	2862.77	1067.66	181.96	75.49	2092.57	0.00	8.41	0.00	22.03	37245.19
Sichuan	54455.07	26982.91	7994.62	6437.22	4717.35	975.29	478.90	9402.27	68.62	79.54	0.00	72.98	111664.77
Guizhou	4113.39	4342.94	1160.12	281.24	2193.30	10.43	5.35	293.62	3.74	68.52	0.00	10.38	12483.02
Yunnan	8877.14	7141.66	2427.39	1201.45	3346.47	17.31	4.33	444.86	2.40	100.16	0.00	16.59	23579.77
Tibet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.11
Shaanxi	4361.26	2457.83	1130.15	150.59	1119.69	9.24	6.11	272.46	0.00	0.00	0.00	66.27	9573.60
Gansu	194.44	51.72	114.60	23.69	80.04	2.63	0.00	0.89	0.00	0.00	0.00	20.70	488.72
Qinghai	1.78	0.00	1.23	5.77	4.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.92
Ningxia	2564.17	1528.67	1196.63	390.05	1570.36	0.00	0.00	0.33	0.00	0.00	0.00	53.50	7303.73
Xinjiang	3915.23	1559.89	1427.83	335.56	778.48	32.73	0.00	127.64	0.00	0.00	0.00	171.94	8349.30

Table 4: The annual carbon sink from freshwater aquaculture products by Chinese provinces in 2023 (excluding feed culture, 10,000 tons).

	Fish	Crustaceans	Shellfish	Total
Beijing	191.52	0.00	0.00	191.52
Tianjin	282.38	54.23	12.50	349.11
Hebei	5461.12	250.47	0.10	5711.69
Shanxi	51.94	1.43	0.00	53.37
Inner Mongolia	1345.54	3.19	30.00	1378.73
Liaoning	4201.12	343.75	0.00	4544.87
Jilin	2467.08	1938.42	23.60	4429.10
Heilongjiang	6972.14	0.99	75.20	7048.33
Shanghai	66.78	0.99	0.00	67.77
Jiangsu	14823.90	2668.49	4744.18	22236.57
Zhejiang	17231.20	1538.35	2534.19	21303.74
Anhui	9840.18	2135.21	874.30	12849.69
Fujian	6896.96	578.93	1754.79	9230.68
Jiangxi	3609.62	335.28	197.40	4142.30
Shandong	11502.12	1781.23	327.70	13611.05
Henan	13120.66	1208.24	540.30	14869.20
Hubei	2519.30	344.74	25.10	2889.14
Hunan	142.80	17.71	49.10	209.61
Guangdong	8015.70	1119.14	631.00	9765.84
Guangxi	9508.80	500.50	675.10	10684.40
Hainan	1484.42	31.90	165.60	1681.92
Chongqing	0.00	0.00	0.00	0.00
Sichuan	0.00	0.00	0.00	0.00
Guizhou	552.58	41.69	1.30	595.57
Yunnan	3735.34	214.06	23.30	3972.70
Tibet	0.00	0.00	0.00	0.00
Shaanxi	0.00	0.00	0.00	0.00
Gansu	0.00	0.00	0.00	0.00
Qinghai	499.66	392.59	0.00	892.25
Ningxia	948.22	2.09	0.00	950.31
Xinjiang	1714.30	37.40	0.00	1751.70

fishing ban" strategy of the Yangtze River. The large-water ecological fishery and rice-fish integrated culture provide infinite possibility and broad space for the development of carbon sink in freshwater fisheries. Strengthen the protection of rare and endangered species, carry out important habitat restoration, strengthen the investigation and monitoring of resources and strengthen the prevention and control of exotic species, accelerating ecological restoration is the key to the combination of carbon sink in freshwater fisheries and the "Ten-year fishing ban" strategy of the Yangtze River.

CONCLUSION

The large-water ecological fishery and rice-fish integrated culture provide infinite possibility and broad space for the development of carbon sink in freshwater fisheries. Strengthen the protection of rare and endangered species, carry out important habitat restoration, strengthen the investigation and monitoring of resources, and strengthen the prevention and control of exotic species, accelerating ecological restoration is the key to the combination of carbon sink in freshwater fisheries and the "Ten-year fishing ban" strategy of the Yangtze River.

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Disclaimers

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Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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