Mathematical Biosciences and Engineering

MBE, 19(6): 5409–5427.
DOI: 10.3934/mbe.2022254
Received: 03 January 2022
Revised: 21 March 2022
Accepted: 21 March 2022
Published: 25 March 2022

http://www.aimspress.com/journal/MBE

Research article

Forecasting algae and shellfish carbon sink capability on fractional order accumulation grey model

Haolei Gu and Kedong Yin*

School of Management Science and Engineering, Shandong University of Finance and Economics, Jinan 250014, Shandong, China

* **Correspondence:** Email: yinkedongsdufe@126.com; Tel: +13370858778; Fax: +13370858778.

Abstract: Marine biology carbon sinks function is vital pathway to earned carbon neutrality object. Algae and shellfish can capture CO_2 from atmosphere reducing CO_2 concentration. Therefore, algae and shellfish carbon sink capability investigate and forecast are important problem. The study forecast algae and shellfish carbon sinks capability trend base on 9 China coastal provinces. Fractional order accumulation grey model (FGM) is employed to forecast algae and shellfish carbon sinks capability. The result showed algae and shellfish have huge carbon sinks capability. North coastal provinces algae and shellfish carbon sinks capability trend smoothness. South and east coastal provinces carbon sinks capability trend changed drastically. The research advised coastal provinces defend algae and shellfish population, expand carbon sink capability. Algae and shellfish carbon sink resource will promote environment sustainable develop.

Keywords: marine carbon sinks capability; algae and shellfish; FGM

1. Introduction

Marine biology carbon sink is critical pathway to earned carbon neutrality object. Marine absorbing 1/3 anthropogenic CO_2 emitted over the industrial period [1]. Marine CO_2 carbon sinks volume gradually increased from 2008–2019 [2]. Greenhouse effect increased surface-ocean CO_2 partial pressure. Marine carbon sink function influenced 10–40% carbon sinks capability variation on 1900–2010 [3]. Northern Indian Ocean evidence shown biological pump transforms CO_2 partial to inorganic carbon storage in deep ocean, reduced greenhouse effect efficiently [4]. Marine carbon sink capability is susceptible and alterable. Mesoscale ocean fronts upwelling increased carbon particle vertical transport and sequestration capability [5]. Anthropogenic CO_2 emitted to aggravate seawater acidulated. Seawater acidulated dissolution marine organism carbonates shell and also reduced marine organism carbonate storage carbon capability. Atmosphere-marine carbon cycles efficiently is critical factor of global ecological system sustainable operated [6]. Marine carbon sinks also will influence global political. Global marine carbon sinks are future international climate negotiations vital topic [7]. Marine carbon sinks process faced multiple challenges. Marine carbon sinks poor data limit relevant research. The Southern Ocean data-poor problem regions restrict air-ocean CO_2 fluxes research [8]. As same time, marine carbon sinks research ought to attention region characteristic. Regional-scale studies is significantly in Continental shelf air-sea CO_2 fluxes capability problem [9]. Literature review evidence has confirmed marine carbon sinks function. However marine carbon sinks capability influence by numerous external factors. Therefore, regional marine biological carbon sinks capability review is vital to alter warming trend.

Carbon sinks fishery is a well-qualified ecological and economic value biological carbon sinks system. Algae and shellfish are important fishery carbon sinks resources. Phototrophic dinoflagellates, cryptomonads, diatoms, heterotrophic bacteria and heterotrophic dinoflagellates algae can efficiently absorb and storage carbon from atmosphere [10]. Shellfish absorb carbon and other nutrient with shell and biological tissue from marine ecosystem to reduce seawater carbon concentration. Seawater carbon negative pressure formed new carbon sink power. Shellfish rope farming model carbon sinks capability is considerably over bottom seeding breeding model [11]. Norway proof showed cod and algae fishery source management optimize bring ecological and economic win-win result [12]. Algae and shellfish polyculture method carbon sediment rate is obviously higher than other regions in Sanggou bay [13]. In marine ecosystem, small copepod ingests storage enormous carbon and transport to metazoan [14]. Mangroves and seagrass are important tool to combating greenhouse effect, reasonable accurately assess carbon sequestration rate has benefit to incent ecosystem sustainable develop [15]. Marine ecosystem pollution will lead biology carbon sinks performance decreasing. In estuary habitat, marine pollutant accumulated in black rockfish from food chain. Yaquina Bay estuary habitat environment change will have negative influence on ocean organism nursery function [16]. Coral ingests micro plastics cause corals feeding impairment, microbiome gene expression error and appearance construction changed [17]. Shellfish carbon sinks capability has seasonal variation characteristics [18]. Ecosystem relies on specific environment condition. Environmental change sensitivity heterogeneity caused marine organism carbon sinks capability changed on different regional [19]. Therefore, algae and shellfish carbon sinks capability study not only helpful for earned carbon neutrality object, but also have benefit of solving marine environment comprehensive management problem. Algae and shellfish carbon sinks capability is alterable. Algae and shellfish carbon sinks capability were more sensitive to environment. Hence algae and shellfish carbon sinks capability forecast is a difficulty problem.

Algae and shellfish statistical data are limited. Algae and shellfish carbon sinks capability influence mechanism is not entirely identified. Hence Algae and shellfish carbon sinks capability forecast is a grey problem. Grey problem used in poor information environment and not entirely known problem typically. Deng definition grey problem concept means half known and half unknown problem [20]. Lei et al. built a training learned prediction grey model according to neural ordinary differential equations [21]. Kang et al. change tradition accumulation and derivative orders from constants to functions. Variable order fractional model can accurately predict complex system characteristic [22]. In complex network perspective, Xie et al. proposed generalized conformable fractional grey model and describe grey model physical meaning [23]. Jiang et al. improve a nonlinear grey Bernoulli model and use whale optimization algorithm calculate grey Bernoulli model parameters [24]. Grey model has widely used in environment source development and protection. Yu considers photovoltaic engineering has high flexibility time-delayed power effect characteristic. Grey model applies to photovoltaic have accurately prediction result [25]. Xu et al. proposed conformable fractional accumulation grey model to analyze energy consumption and carbon dioxide emission relationship [26]. Grey model also used in assessing PM2.5 seasonal fluctuation and marine fleets CO_2 emissions [27,28]. Tu & Chen forecast pubic attention to air pollution according to designing a new unequal adjacent grey model [29]. Ding et al. [30–32] presented a series of grey models to analyzing nuclear energy consumption, photovoltaic power generation and new energy vehicles sale problem. The forecast accuracy results confirmed the new grey model has the highest forecasting precision, small results empirical volatility, and outcome generalizability characteristics. Wang et al. [33] presented a multivariate forecasting model to analyzed energy consumption influenced factor, the result showed new grey model had better forecast precision. Zeng et al. [34,35] applied improved grey system model to predicted China coalbed methane production, and realized shale China gas production scientific prediction based on the new information priority principle combined with grey buffer operator technology.

Previous studies have provided algae and shellfish carbon sinks function is vital to control greenhouse effect. However, less researcher applies grey model to forecast fundamental fishery product like algae and shellfish carbon sinks capability alteration trend. Algae and shellfish carbon sinks capability influence factors are incomplete full known. Algae and shellfish carbon sinks capability correlation research data also in poor information situation. Therefore, the study applies FGM to analyze algae and shellfish carbon sinks capability. In the research, the major innovation as follow: 1) Algae and shellfish carbon sinks capability analyzes and forecast. Algae and shellfish marine carbon sinks are artificial enhance carbon sinks method. Algae and shellfish carbon sinks capability analyze will appraise algae and shellfish carbon sinks capability and develop trend. 2) Research result can provide policy advice for future marine carbon sinks fishery industry to enhance marine carbon sinks fishery policy scientific.

This study is organized as follows: Section 2 analyzes algae and shellfish carbon sinks capability mechanism. Section 3 provides data detail and grey model method choice. Section 4 analyzes study result according to geographic position. Section 5 drew conclusion and implication from study result.

2. Algae and shellfish carbon sinks mechanism

Algae and shellfish are important marine economic merchandise. Previous research has testified algae and shellfish can sinks enormous carbon from atmosphere. Algae and shellfish merchandise are nutrient rich, is very important seafood of China. As Chinese traditional marine product, algae and shellfish have high market recognition degree. Algae and shellfish being farmed have a protracted history. Seawater breeding algal and shellfish technology are mature. Algae and shellfish breed may also achieve ecology benefit. Algae and shellfish breed and catch can remove marine ecology interior carbon source and create a sustainable marine carbon sinks system. Coastal area algae and shellfish breeding can achieve economic and ecological win-win result.

2.1. Algae carbon sinks mechanism

Marine carbon sinks fishery is breed marine organisms carbon sinks function to extend marine carbon sinks capability. Marine carbon sinks fishery is considerably totally different to traditional fishery. Marine carbon sinks fishery aims to increasing marine carbon sinks capability. Algae is primary producer in marine ecosystem. Influence by photosynthesis, algae use inorganic carbon and nutrients in seawater to build biological tissues. Algae absorbs carbon from seawater can reduce surface-ocean CO_2 partial pressure promote atmosphere carbon dioxide dissolved in marine. Additionally, algae breeding forestalls seawater acidification.

2.2. Shellfish carbon sinks mechanism

Shellfish also play an important role in marine carbon sinks function. shellfish shells use carbon element to form calcium carbonate. Shellfish also requires carbon to create soft tissue [36]. Shellfish and algae unite breed will efficiency improve fishery economy and environment performance. Algae provides survival necessary bait to shellfish. Shellfish excretory product provides abundant nutrients for algae upgrowth. Algae and shellfish comprehensive carbon sink function significant. Algae carbon content is 20–35% of algae net weight. Shellfish soft tissue carbon content is 26–42% soft tissue netted weight. Shellfish shell carbon content is 11–13% of shell net weight [37]. Shellfish tissue forms process need to converge carbon in marine element. Shellfish soft tissue and shell storage huge carbon element from marine. Therefore, shellfish breed and catch are vital pathway to increase marine carbon sink capability.

2.3. Marine carbon sinks capability influence mechanism

Marine carbon sinks fishery is increasing marine ecosystems carbon sinks capability vital anthropogenic. Marine organisms will storage carbon in internal tissue. Marine environment change has knock-on effect on Marine organism [38]. Algae and shellfish have crucial role in marine carbon sinks system. Photosynthesis dissolved CO_2 to inorganic in seawater. Atmosphere CO_2 transforms CO_3 in seawater. Photosynthesis provides necessary energy for algae grow. Algae photosynthesis transforms H_2O and CO_2 into the carbohydrates and energy. Shellfish is feed by algae, plankton, and small copepod. Shellfish predation processes to shift other organism carbon in shellfish tissue internal. Algae and shellfish death and deposition cause organism tissue interior carbon form changed. Algae and shellfish death tissue carbon part transformed into particulate organic carbon form and permanently trapped in ocean floor. The other carbon transformed into dissolved organic form of storage carbon. Marine microbial carbon pumps transform dissolved organic carbon into refractory dissolved organic carbon form and transferred to deep-sea storage. Marine environment changes influence biological pumps transform and storage carbon efficient. Marine environment reason like temperature and climate affect algae and shellfish carbon sinks capability. Marine pollution and anthropogenic improper intervention inhibit ocean carbon sinks capability. Algae and shellfish carbon sinks mechanism is shown in Figure 1.

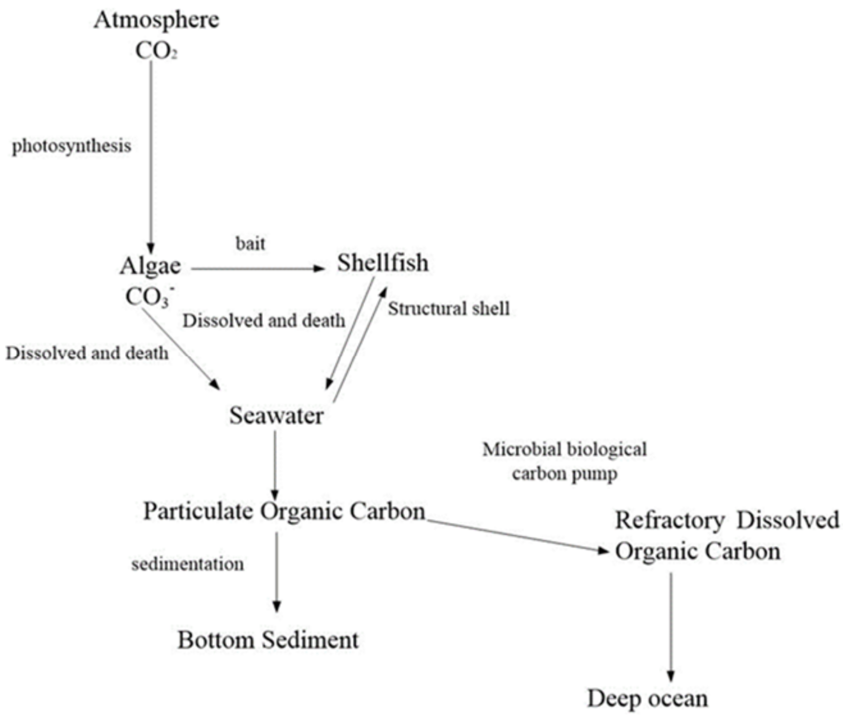

Figure 1. Algae and shellfish carbon sinks mechanism.

3. Data and methods

3.1. Research region

As show in Figure 2, China 9 coastal provinces latitude span widely. China 9 coastal provinces climate different. Northernmost Liaoning province is medium latitudes monsoon climate. Liaoning province average temperature is higher than 0 ℃. Liaoning four seasons distinct, summer is hot and rainy, winter is cold and dry. Southernmost Hainan province is tropical monsoon climate. Tropical monsoon climate area has high temperature throughout year, average temperature above 22 °C, the coldest month above 18 °C. Other provinces climate characterizes also different. Climate influences coastal provinces temperature, precipitation and marine environment significantly. China coastal province is the busiest economic belt. Coastal area marine traffic, urbanization, export-oriented economic, anthropogenic activity intimate related to marine environmental quality. China has achieved great success in economy development. But China 9 coastal provinces industry, environment and climate reasons lead algae and shellfish carbon sinks capability different significant. Hence, it is necessary to analyze and forecast China 9 coastal provinces carbon sinks capability respectively.

Figure 2. China 9 coastal province geographical location.

The research study China 9 coastal provinces algae and shellfish carbon sinks capability trend for three reasons:

1) Geographical location leads marine biological community China 9 coastal provinces distinction considerably. Biological community and fishery industry pattern decide marine carbon sinks capability. Temperature and precipitation impact to surface ocean CO_2 partial pressure and seawater dissolved CO_2 in atmosphere efficiency. Temperature and illumination also impact organic carbon particulate dissolved, transform and storage. China 9 coastal provinces algae and shellfish carbon sinks capability study has benefit to marine ecology producer and consumer carbon sinks capability research.
2) China 9 coastal provinces industry pathway is different. Anthropogenic industrial behavior affects marine environment. Marine natural environment and anthropogenic effect marine carbon sinks capability. China 9 coastal provinces algae and shellfish carbon sinks capability study will have benefit to know algae and shellfish in differently environment regional. The study will also assess industrial pattern influence algae and shellfish carbon sinks capability.
3) Coastal province marine carbon sinks capability studies are important to enhance regional environment policy rationality. Algae and shellfish carbon sinks capability study can help to quantify analyze algae and shellfish carbon sinks prospect. Government administrator can formulate carbon discharge task in comprehensively economic society influence factor.

3.2. Data source

Algae and shellfish marine catch amount and breed amount reflect regional marine carbon sinks capability. Organism weight and carbon sinks coefficient can estimate algae and shellfish carbon sinks capability. Marine algae and shellfish catch and breed amount can reflect coastal regional algae and shellfish resource carbon sinks capability sufficiently. According review previous research [39], algae and shellfish carbon sinks capability can estimate according to organisms' weight and carbon sink ratio. The study chose organism weight to analyze and forecast algae and shellfish carbon sinks capability. Algae and shellfish carbon sinks capability calculate method as shown:

1) Total carbon sinks capability

$$C_t = C_a + C_s \tag{1}$$

C_t mean algae and shellfish total carbon sinks capability in 9 coastal provinces; C_c means algae carbon sinks capability; C_s means shellfish carbon sinks capability.

2) Algae carbon sinks capability

$$C_a = (C_{\mathrm{a,c}} + C_{\mathrm{a,b}}) * \omega a * \zeta a \tag{2}$$

$C_{\mathrm{a,c}}$ means algae caught amount; $C_{\mathrm{a,b}}$ means algae breed amount; ωa means algae dry weight/total weight coefficient, algae weight/total weight coefficient is 20%; ζa means algae carbon sinks coefficient. Algae carbon sinks coefficient is 0.27.

3) Shellfish carbon sinks capability

$$\begin{gathered} Cs = Cf + Ct \\ Cf = (C_{\mathrm{s,c}} + C_{\mathrm{s,b}}) * \omega s * \theta f * \zeta \mathrm{s,f} \\ Ct = (C_{\mathrm{s,c}} + C_{\mathrm{s,b}}) * \omega s * \theta s * \zeta \mathrm{s,s} \end{gathered} \tag{3}$$

Cf means shellfish shell carbon sink capability; Ct means shellfish soft tissue carbon sink capability; $C_{\mathrm{s,c}}$ means shellfish caught amount; $C_{\mathrm{s,b}}$ means shellfish breed amount; ωs means shellfish dry weight/total weights, shellfish dry weight/total weights value is 65%; θf means shellfish shell dry weight/total dry weight coefficient, shellfish shell weight/total weights coefficient is 93%; $\zeta \mathrm{s,f}$ means shellfish carbon sinks coefficient. shellfish shell carbon sinks coefficient is 0.13; θ_s means shellfish soft tissue dry weight/total dry weight coefficient, shellfish soft tissue weight/total weight coefficient is 7%; $\zeta s, \mathrm{s}$ means algae carbon sinks coefficient. Algae coefficient carbon sinks coefficient is 0.46.

China 9 coastal provinces algae and shellfish marine catch and breed amount were collected in *Chinese fishery Statistical yearbook* from 2011–2020. *Chinese fishery Statistical yearbook* has one year hysteresis reflect algae and shellfish marine catch amount statistics value from 2011 to 2019. According calculation China 9 coastal provinces algae and shellfish carbon sinks capability statistical data in Table 1.

Table 1. China 9 coastal provinces algae and shellfish carbon sinks capability.

carbon sinks capability(t)	liaoning	hebei	shandong	jiangsu	zhejiang	fujian	guangdong	guangxi	hainan	total
2011	208519.3	28962.65	368974.8	73145.42	70474.74	260582.3	193457.7	73908	6537.983	1280036
2012	235663.4	35913.47	386483.1	74662.77	66694.82	267185.4	195793.9	77663.6	7081.066	1342073
2013	253459.2	42808.37	402419.4	77429.35	73838.7	281826.7	200471.2	60329.07	7593.667	1400386
2014	258806.6	46701.99	421257.3	76063.46	76031.81	298459.2	203240.1	84777.53	9100.467	1467352
2015	262659.4	47983.84	440217	71664.82	79402.67	313269.3	206784.9	89551.56	9546.095	1513548
2016	277998.6	47771.78	456897.8	72861.71	86442.39	333125.3	209326.5	94336.34	9187.803	1580776
2017	270177.3	49213.55	461592.6	74175.32	98480.48	340158.8	195013.3	98221.31	8422.673	1589050
2018	252223.8	45023	463186.6	72827.92	102356	365614.4	197581.1	102705.2	5631.969	1603536
2019	252963.9	37806.72	440084.8	72575.33	107386.9	389836.5	199768.6	106054.9	4393.08	1608497

3.3. Fractional order accumulation grey model

Wu et al. [40] present fractional order accumulation to better reflect new information priority theory. Compared with traditional grey model, fractional order accumulation grey model introduced fractional order to prevent traditional small sample grey model forecasts outcome error. FGM (1,1) deals method is:

Step1: Assume non-negative sequence $X^{(0)} = \{x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n)\}$, For $\zeta \in (0,3]$, (According to particle swarm optimization test optimum range), ζ −order accumulation generating operator (ζ-FGM) is defined as follows:

$$x^{(\zeta)}(k) = \sum_{i=1}^{k} C_{k-i+\zeta-1}^{k-i} x^{(0)}(i), k = 1,2, \cdots, n$$

Where $C_{\zeta-1}^{0} = 1; C_{k}^{k+1} = 0; C_{k-i+\zeta-1}^{k-i} = \frac{(k-i+\zeta-1)(k-i+\zeta-2)\ldots(\zeta+1)\zeta}{(k-i)!}$.

When ζ =1, $C_{k-i+\zeta-1}^{k-i} = C_{k-i}^{k-i} = 1$ ζ -FGM is defined as $x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i)$ equal to traditional 1-AGO grey model in GM (1,1).

Step 2: FGM (1,1) model establish as:

$$\frac{dx^{(\zeta)}}{dt} + ax^{(\zeta)} = b; \qquad x^{(\zeta)}(1) = x^{(0)}(1)$$

In FGM (1,1) model a,b are parameters and u is the control parameter. Solution FGM (1, 1) parameters with least-squares

$$\begin{bmatrix} \hat{a} \\ \hat{b} \end{bmatrix} = (B^T B)^{-1} B^T Y$$

where

$$B=\begin{bmatrix} -\frac{x_1^{(\zeta)}(1)+x_1^{(\zeta)}(2)}{2} & 1 \\ -\frac{x_1^{(\zeta)}(2)+x_1^{(\zeta)}(3)}{2} & 1 \\ \vdots & \vdots \\ -\frac{x_1^{(\zeta)}(n-1)+x_1^{(\zeta)}(n)}{2} & 1 \end{bmatrix}$$

$$Y=\begin{bmatrix} x_1^{(\zeta)}(2)-x_1^{(\zeta)}(1) \\ x_1^{(\zeta)}(3)-x_1^{(\zeta)}(2) \\ \vdots \\ x_1^{(\zeta)}(n)-x_1^{(\zeta)}(n-1) \end{bmatrix}.$$

Step 3: FGM (1,1) approximate function is:

$$\hat{x}^{(\zeta)}(k+1)=\left(x^{(0)}(1)-\frac{\hat{b}}{\hat{a}}\right)e^{-\hat{a}k}+\frac{\hat{b}}{\hat{a}}$$

Step 4: FGM (1,1) inverse accumulated generating operator in:

$$X^{(\zeta)}=\left\{x^{(\zeta)}(1),x^{(\zeta)}(2),\cdots,x^{(\zeta)}(n)\right\}$$

$$\alpha^{(r)}x^{(0)}=\{\alpha^{(1)}\hat{x}^{(1-r)}(1),\alpha^{(1)}\hat{x}^{(1-r)}(2),\alpha^{(1)}\hat{x}^{(1-r)}(3),\ldots,\alpha^{(1)}\hat{x}^{(1-r)}(n)\}$$

Thus, the fitting values are $\hat{x}^{(0)}(\zeta)=\hat{x}^{(1)}(\zeta)-\hat{x}^{(1)}(\zeta-1)$.

Grey model means absolute percentage error (MAPE) can use to reflect actual value and predicted value error. Low degree MAPE values to reflect perfect forecast precision. MAPE calculates formula is:

$$MAPE=\frac{\Sigma_{t=1}^{n}\left|{(A_t-F_t)}/{A_t}\right|}{n}\times 100\%$$

For better understanding FGM (1,1) solution principle, FGM (1,1) analyze and forecasting process as shown in Figure 3.

FGM (1,1) model forecasting algae and shellfish carbon sinks capability need to evaluate model availability firstly. Apply FGM (1,1), GM (1,1) and DGM (1,1) model evaluate China 9 coastal provinces total algae and shellfish carbon sinks. The forecast result as shown in Figure 4.

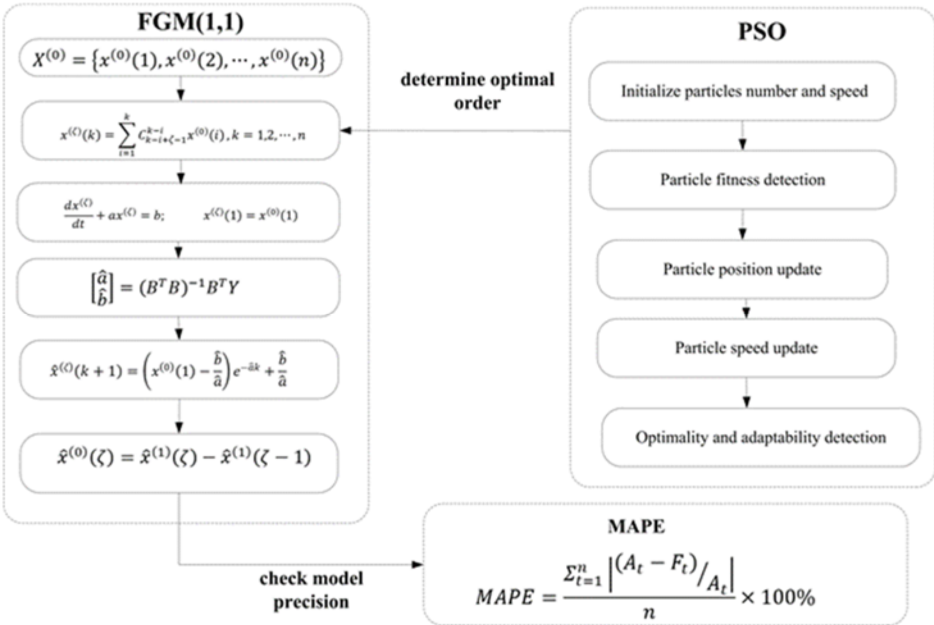

Figure 3. Algae and shellfish carbon sink capability forecasting process.

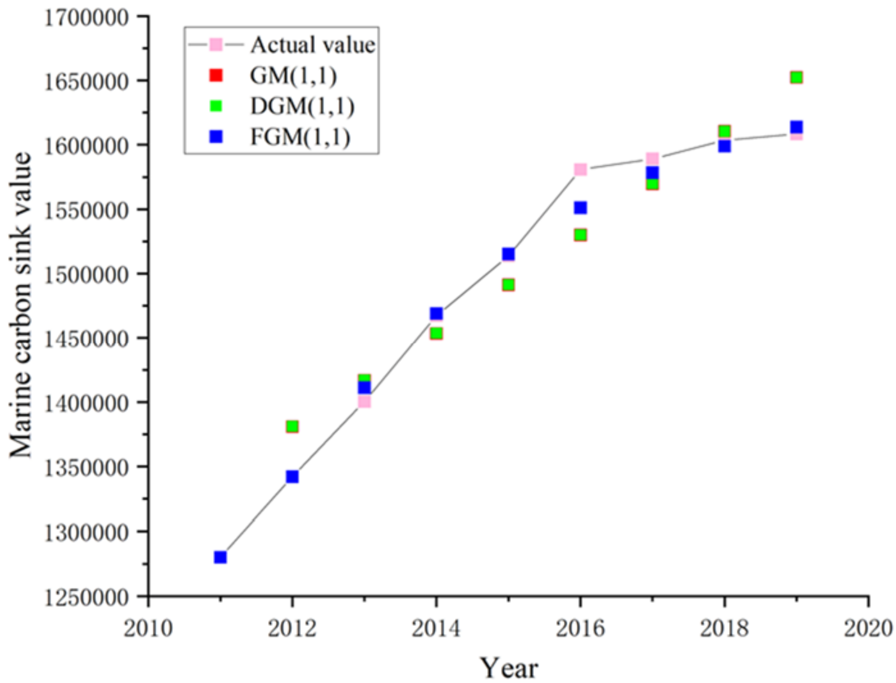

Figure 4. Grey model forecast precision result.

FGM (1,1) new information priority target realized according to fractional accumulation. Particle swarm optimization applied to optimize fractional-order (r = 0.0633). Algae and shellfish carbon sinks capability apply FGM $^{(0.0633)}$ (1,1) forecast MAPE is 0.51%. Forecast result superior than GM (1,1) (MAPE is 2.7%) and DGM (1,1) (MAPE is 1.7%). Hence, FGM (1,1) is more suitable to forecast algae and shellfish carbon sinks capability. Therefore, FGM (1,1) applied to empirical study algae and shellfish carbon sinks capability.

4. Empirical study

4.1. North coastal province empirical result

As show in Figure 5 north coastal provinces algae and shellfish carbon sinks capability on downward trend. According to north coastal province shellfish and algae catch and breed statistics data: Liaoning, Hebei and Shandong three provinces future four years forecast trend will continue decrease. Liaoning shellfish caught and breed amount enormous. In 2016 Liaoning algae and shellfish catch and breed carbon sinks capability has a precipitous decrease. Liaoning proof showed marine carbon sinks capability environment recovered process slowly. Marine carbon sinks modernization is a complexity economic and ecological problem. Industry activity not only effects tradition forest carbon sinks capability, but also effect marine carbon sinks capability. Marine carbon sinks capability recovered must govern environment pollution comprehensively. Through Section 3 Liaoning FGM (1,1) approximate function is:

$$\hat{x}^{(0.665)}(k+1) = \left(x^{(0)}(1) - 2149090\right)e^{-0.0893k} + 2149090$$

FGM (1,1) forecast future four years algae and shellfish carbon sinks capability result show Liaoning will still in decrease trend in future four years. The trend means anthropogenic activity frequently caused marine carbon sinks capability decreased important factor. Liaoning balance economic develops and ecological protect are realize social high-quality development vital task. If Liaoning to continue neglect marine carbon sinks capability recovers, Liaoning algae and shellfish carbon sinks capability will continue damage.

Hebei province algae and shellfish carbon sinks capability also in decrease trend. Algae and shellfish carbon sinks capability decrease in 2018 and 2019 sharply. Marine environment changes lead algae and shellfish catch and breed amount decreased. Bohai bay environmental pollution reduced algae and shellfish carbon sinks capability. Hebei province carbon sinks capability decreased with jin-jing-ji speedily economy developed. Hebei province blends in capital economic circle is an important advance opportunity. But capital economic circle changed Hebei province fishery economy model. Jin-jing-ji integration drives more fishermen to other job. The Bohai bay chiefly fishery function was replaced by commerce and transport function. Tradition fishery faced transformation and upgrading pressure. Algae and shellfish catch and breed carbon sinks capability decreased. Through Section 3 FGM (1,1) approximate function is:

$$\hat{x}^{(0.38)}(k+1) = \left(x^{(0)}(1) - 122872.9\right)e^{-0.2431k} + 122872.9$$

FGM (1,1) forecast future four years algae and shellfish carbon sinks capability result show Hebei province future carbon sinks in decrease trend. It means economic transformation process also changed carbon sinks capability. As tradition coal consumption province, Hebei carbon sinks pressure seriously. The study treads shown if Hebei province ignores algae and shellfish carbon sinks capability function, Hebei carbon sinks capability will continuous declination.

Shandong province algae and shellfish carbon sinks capability continue increase from 2011–2018 but decrease in 2019. Shandong province algae and shellfish carbon sinks organism community decrease influence Shandong marine carbon sinks capability. Algae and shellfish organism community catch and breed decrease in 2019 means Shandong province fishery industry transform and upgrade decrease algae and shellfish carbon sinks function. Heavy industry CO_2

discharged sinks by algae and shellfish hardly. Through Section 3 FGM (1,1) approximate function is:

$$\hat{x}^{(0.248)}(k+1) = \left(x^{(0)}(1) - 944486\right)e^{-0.2028k} + 944486$$

FGM (1,1) forecast future four years algae and shellfish carbon sinks capability result show Shandong province carbon sinks capability in a fluctuate trend, future carbon sinks capability faced decrease risk. Carbon neutralized pressure drove Shandong province paid highly attention to marine carbon sinks function. Shandong province transform economy advance model and applies cleaner energy to reduce carbon sinks pressure. But fish culture structure changed marine algae and shellfish carbon sink capability. Shandong province marine primary industry ratio decreasing means more resources is tilted towards other industries. Hence, future Shandong province algae and shellfish carbon sinks capability will in decrease trend.

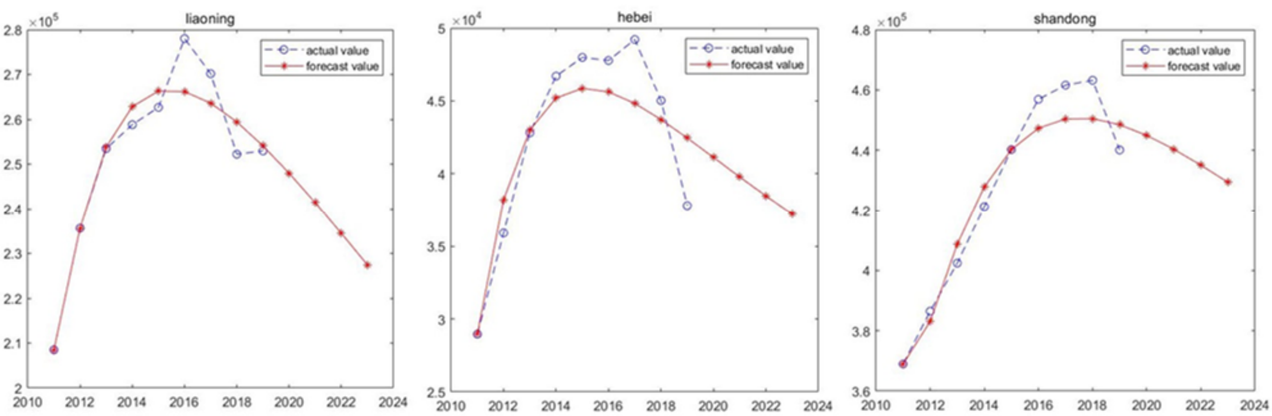

Figure 5. North coastal provinces FGM (1,1) forecast result.

4.2. Middle coastal province empirical result

As show in Figure 6, middle coastal provinces algae and shellfish carbon sinks capability forecast result in general increase. According to south coastal province shellfish and algae catch and breed statistics data: Jiangsu, Zhejiang, Fujian three provinces future four years forecast trend also shown in Figure 6. Jiangsu, Zhejiang, Fujian are traditional fishery regional. Zhejiang and Fujian algae and shellfish carbon sinks capability in increase trend, but Jiangsu in decrease trend. Jiangsu algae and shellfish carbon sinks decrease significantly. Jiangsu province fishery carbon sinks depend algae and shellfish in low degree. Algae and shellfish carbon sinks capability fluctuate forceful. Through Section 3 FGM (1,1) approximate function is:

$$\hat{x}^{(0.054)}(k+1) = \left(x^{(0)}(1) - 83865\right)e^{-0.713k} + 83865$$

FGM (1,1) forecast future four years result show Jiangsu province carbon sinks capability in a decrease trend. As traditional abundant place, Jiangsu province algae and shellfish carbon sinks capability are influenced by environment pollution and marine disaster. Algae and shellfish carbon sinks capability in future four years will continue decrease. Therefore, Jiangsu province should control marine pollution and prevent marine disaster seriously.

Zhejiang province algae and shellfish carbon sinks capability has significance increase. Zhejiang is traditional marine fishery province. Benefit from marine comprehensive management and protect ability, algae and shellfish carbon sinks capability continue increase. Zhejiang province paid high attention to algae and shellfish absorb greenhouse gas function. Zhejiang province had long history to breed and catch algae and shellfish. Algae and shellfish breed have advanced management technology. Nowadays, Zhejiang province algae and shellfish technology advantage enhance regional carbon sink capability. Zhejiang province algae and shellfish carbon sinks capability continue increase from 2011-2019. Through Section 3 FGM (1,1) approximate function is:

$$\hat{x}^{(0.995)}(k+1) = \left(x^{(0)}(1) + 859557\right)e^{0.0689k} - 859557$$

FGM (1,1) forecast future four years algae and shellfish carbon sinks capability. Forecast results shown Zhejiang province algae and shellfish carbon sinks capability in increase trend. In future four years Zhejiang province algae and shellfish carbon sinks capability will increase sharply. Zhejiang province algae and shellfish will play vital function in sinks atmosphere CO_2. Algae and shellfish advanced management technology drive construct more controllable carbon sinks resource in Zhejiang province. Anthropogenic created algae and shellfish carbon sinks resource have efficient and sustainable characteristic.

Fujian province algae and shellfish carbon sinks capability has significance increase. Fujian province is also a traditional marine fishery province. Marine breed and catch fishery have long history. Fujian province paid high attention to algae and shellfish catch, breed and protect. Fujian province storm surge disaster frequently. Aim to reduce marine disaster cause algae and shellfish carbon sinks capability reduction, Fujian province formulate especially marine disaster contingency plan to protect algae and shellfish from marine disaster damage. Through Section 3 FGM (1,1) approximate function is:

$$\hat{x}^{(0.998)}(k+1) = \left(x^{(0)}(1) + 4712733\right)e^{0.052k} - 4712733.$$

FGM (1,1) forecast future four years algae and shellfish carbon sinks capability result shown Fujian province algae and shellfish carbon sinks capability in increase trend. Fujian province algae and shellfish breed high efficiently, carbon sink function remarkable. Anthropogenic protected algae and shellfish resource is the reason of carbon sinks capability increase sharply. Fujian province anthropogenic intervenes marine disaster measures to bring healthy growing environment for marine organism, reduce marine disaster damage algae and shellfish carbon sinks capability.

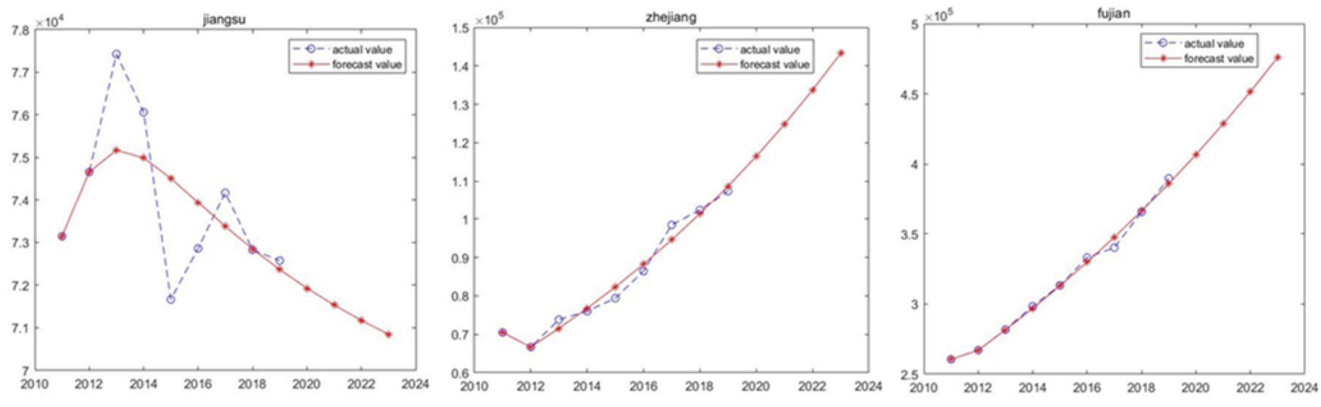

Figure 6. Middle coastal provinces FGM (1,1) forecast result.

4.3. South coastal province empirical result

As show in Figure 7, south coastal provinces include Guangdong, Guangxi and Hainan three provinces. According to south coastal province algae and shellfish catch and breed statistics data Guangdong, Guangxi and Hainan three provinces future four years forecast trend also shown in Figure 7. Guangdong industry and urbanization have occupied marine fishery space. Aquaculture unregulated used drugs to aggravate marine pollution led red tide disasters. Red tide disaster caused algae and shellfish carbon sinks capability decrease seriously. Marine environment repairs to reduce algae and shellfish catch and breed area. Marine environment regulation reduced low quality and high pollution breed area. Therefore, Guangdong algae and shellfish carbon sinks capability decrease. Through Section 3 FGM (1,1) approximate function is:

$$\hat{x}^{(0.135)}(k+1) = \left(x^{(0)}(1) - 289647\right)e^{-0.3486k} + 289647.$$

FGM (1,1) forecast future four years algae and shellfish carbon sinks capability result shown Guangdong province algae and shellfish carbon sinks capability in decrease trend. Guangdong-Hong Kong-Macao greater bay area high marine environment standard and environment regulation will continue to reduce algae and shellfish catch and breed area. Traditional simpleness and low-quality algae and shellfish breed area will vanish. In FGM (1,1) forecast result, Guangdong province algae and shellfish catch and breed carbon sinks capability will continue appear decrease trend.

Algae and shellfish carbon sinks in Guangxi province has continue increase. Guangxi province paid high attention to apply high-quality algae and shellfish breed technology. Guangxi province algae and shellfish catch and breed carbon sinks capability increase from 2014–2019.The phenomenon reflect Guangxi province fishery economic already received remarkable achievement in marine carbon sinks function. At the other side, algae and shellfish carbon sinks need support by high-quality breed technology. Traditional algae and shellfish breed not only decrease carbon sinks capability, but also cause marine pollution problem. Through Section 3 FGM (1,1) approximate function is:

$$\hat{x}^{(0.486)}(k+1) = \left(x^{(0)}(1) + 1526515\right)e^{0.0216k} - 1526515.$$

FGM (1,1) forecast future four years algae and shellfish carbon sinks capability result show Guangxi province algae and shellfish carbon sinks capability in increase trend. Guangxi province high-quality technology expand anthropogenic breed algae and shellfish biological community. Anthropogenic removed carbon from marine in time can recover marine carbon sinks capability efficiently, prevent marine become new atmosphere CO_2 source. In FGM (1,1) forecast result, Guangxi province algae and shellfish catch and breed carbon sinks capability will continue in increase trend.

Hainan province algae and shellfish carbon sinks capability continue increase from 2011–2015 but decrease in 2016–2019. Hainan province algae and shellfish carbon sinks organism community changed influence Hainan marine biological carbon sinks capability. Algae and shellfish carbon sinks function in Hannan province appear decrease trend. Algae and shellfish proportion in Hainan fishery product is low. Algae and shellfish are not mainly carbon sinks resource. After 2015, Hainan province reduced traditional high pollution breed pattern and low efficiently breed area cause algae and shellfish carbon sinks capability decrease. Through Section 3 FGM (1,1) approximate function is:

$$\hat{x}^{(0.845)}(k+1) = \left(x^{(0)}(1) - 87414\right)e^{-0.096k} + 87414.$$

FGM (1,1) forecast future four years algae and shellfish carbon sinks capability result shown Hainan province algae and shellfish carbon sinks capability in decrease trend. Hainan province algae and shellfish catch and breed will be replaced by other marine carbon sinks fishery production. In FGM (1,1) forecast result, Hainan province algae and shellfish catch and breed carbon sinks capability will continue appear decrease trend.

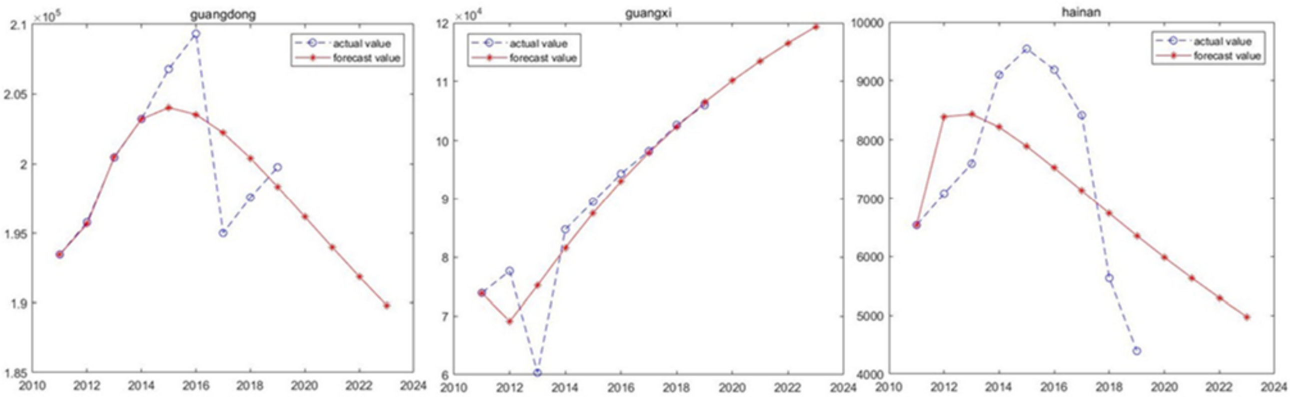

Figure 7. South coastal provinces FGM (1,1) forecast result.

5. Conclusions and implication

Marine carbon sinks function has become important carbon sinks resource. Marine carbon sinks organism like algae and shellfish living environment change will cause carbon sinks capability variation. Marine ecosystem damaged cause algae and shellfish carbon sinks capability descend. Industrial manufacture CO_2 released into atmosphere will not storage and sinks by marine organism. Greenhouse effect and environment pollution will format carbon sinks capability descend vicious cycle. Therefore, in order to better understand shellfish and algae carbon sinks capability in different region is meaningful for excavate shellfish and algae carbon sinks potential and formulate future marine carbon discharge policy. The research used FGM (1,1) model to study algae and shellfish carbon sinks capability in 9 China coastal provinces. According to 9 China coastal provinces shellfish and algae carbon sinks capability research outcome. The research has followed conclusion:

1) Compared with other grey model, FGM (1,1) has more suitable for predict algae and shellfish carbon sinks capability. FGM (1,1) can realize new information first principle according particle swarm optimization confirmed fractional order. FGM (1,1) is more suitable than GM (1,1) and DGM (1,1) to forecast shellfish and algae carbon sinks capability.

2) Marine ecosystem recovered is a slowly produce. Shellfish and algae carbon sinks capability have remarkable difference in 9 China coastal provinces. In the study, 9 China coastal provinces algae and shellfish carbon sinks capability different obviously. It is phenomenon reflect algae and shellfish carbon sinks function realize it is not only a technology problem, but also correlate to policy and breed culture.

3) The study reflects algae and shellfish carbon sinks capability different trend in 9 China coastal provinces regional. Algae and shellfish living state will decide their carbon sinks capability in marine ecosystem. If marine environment continues be polluted, algae and shellfish will absorb CO_2 in atmosphere hardly.

The study already comprehensive research 9 China coastal provinces algae and shellfish carbon sinks capability. The study results have benefit to enhance marine carbon sinks capability in the future. The following suggestions can enhance shellfish and algae carbon sinks capability.

1) Coastal province green development strategic need considering marine carbon sinks function comprehensively. China as the largest developing country. China faced reduction CO_2 emission pressure heavily. Marine carbon sink ecosystem recovered will have positive influence to eliminate industry emission CO_2 pollution.

2) Marine carbon sinks capability development needs nationwide to collaborate. Algae and shellfish carbon sinks function realize need capital and technology collaborate. All coastal provinces regions have responsible to protect marine carbon sinks capability. Marine carbon sinks resource values rational reflection and carbon trade rule enact will have benefit stimulate marine carbon sinks resource developed.

3) Marine carbon sinks capability regains is a system problem. Coastal province should design algae and shellfish carbon sinks resource recovery plan according to marine ecosystem characteristic. Future studies should aim enhance marine carbon sinks breed economic efficiency. Biological carbon sink economic efficiency will influence sinks carbon capability. Marine carbon sinks economical enhance will transfer more resource in optimize ocean carbon sinks capability.

However, the study still has some limitations. Firstly, the study only researched and forecast algae and shellfish carbon sinks capability. Future studies can complete research other marine organism carbon sinks capability. It will have benefit to improve marine carbon sink mechanism research. Secondly, this study only provides Chinese marine carbon sinks evidence. Future research can research marine carbon sinks capability in other social environment background ulteriorly.

Acknowledgments

This study was supported by the Major Social Science Fund Project of China (14ZDB151).

Conflict of interest

The authors declare that they have no conflicts of interest.

References

1. S. Khatiwala, T. Tanhua, S. M. Fletcher, M. Gerber, S. C. Doney, H. D. Graven, et al., Global ocean storage of anthropogenic carbon, *Biogeosciences*, **10** (2013), 2169–2191. https://doi.org/10.5194/bg-10-2169-2013
2. J. Wu, B. Li, Spatio-temporal evolutionary characteristics of carbon emissions and carbon sinks of marine industry in China and their time-dependent models, *Mar. Policy*, **135** (2022), 104879. https://doi.org/10.1016/j.marpol.2021.104879
3. T. DeVries, C. L. Quéré, O. Andrews, Decadal trends in the ocean carbon sink, *Proc. Natl. Acad. Sci. U. S. A.*, **116** (2019), 11646–11651. https://doi.org/10.1073/pnas.1900371116
4. V. V. S. S. Sarma, M. D. Kumar, T. Saino, Impact of sinking carbon flux on accumulation of deep-ocean carbon in the Northern Indian Ocean, *Biogeochemistry*, **82** (2007), 89–100. https://doi.org/10.1007/s10533-006-9055-1

5. M. R. Stukel, L. I. Aluwihare, K. A. Barbeau, A. M. Chekalyuk, R. Goericke, A. J. Miller, et al., Mesoscale ocean fronts enhance carbon export due to gravitational sinksing and subduction, *Proc. Natl. Acad. Sci. U. S. A.*, **114** (2017), 1252–1257. https://doi.org/10.1073/pnas.1609435114
6. C. Ma, K. You, D. Ji, W. Ma, F. Li, Primary discussion of a carbon sink in the oceans, *J. Ocean Univ. China*, **14** (2015), 284–292. https://doi.org/10.1007/s11802-015-2548-6
7. K. Rehdanz, R. S. J. Tol, P. Wetzel, Ocean carbon sinks and international climate policy, *Energy Policy*, **34** (2006), 3516–3526. https://doi.org/10.1016/j.enpol.2005.07.015
8. L. Gloege, G. A. McKinley, P. Landschützer, A. R. Fay, T. L. Frölicher, J. C. Fyfe, et al., Quantifying errors in observationally based estimates of ocean carbon sink variability, *Global Biogeochem. Cycles*, **35** (2021), e2020GB006788. https://doi.org/10.1029/2020GB006788
9. F. Lacroix, T. Ilyina, G. G. Laruelle, P. Regnier, Reconstructing the preindustrial coastal carbon cycle through a global ocean circulation model: was the global continental shelf already both autotrophic and a CO_2 sinks? *Global Biogeochem. Cycles*, **35** (2021), e2020GB006603. https://doi.org/10.1029/2020GB006603
10. H. J. Jeong, Y. D. Yoo, K. Lee, H. C. Kang, J. S. Kim, K. Y. Kim, Annual carbon retention of a marine-plankton community in the eutrophic masan bay, based on daily measurements, *Mar. Biol.*, **168** (2021), 69. https://doi.org/10.1007/s00227-021-03881-4
11. A. Olivier, L. L. Vay, S. K. Malham, M. Christie, J. Wilson, S. Allender, et al., Geographical variation in the carbon, nitrogen, and phosphorus content of blue mussels, *Mytilus edulis*, *Mar. Pollut. Bull.*, **167** (2021), 112291. https://doi.org/10.1016/j.marpolbul.2021.112291
12. G. K. Vondolia, W. Chen, C. W. Armstrong, M. D. Norling, Bioeconomic modelling of coastal cod and kelp forest interactions: Co-benefits of habitat services, fisheries and carbon sinks, *Environ. Resour. Econ.*, **75** (2020), 25–48. https://doi.org/10.1007/s10640-019-00387-y
13. J. Sui, J. Zhang, S. J. Ren, F. Lin, Organic carbon in the surface sediments from the intensive mariculture zone of sanggou bay: Distribution, seasonal variations and dources, *J. Ocean Univ. China*, **18** (2019), 985–996. https://doi.org/10.1007/s11802-019-3768-y
14. A. Roura, J. M. Strugnell, Á. Guerra, Á. F. González, A. J. Richardson, Small copepods could channel missing carbon through metazoan predation, *Ecol. Evol.*, **8** (2018), 10868–10878. https://doi.org/10.1002/ece3.4546
15. J. B. Gallagher, Taking stock of mangrove and seagrass blue carbon ecosystems: A perspective for future carbon trading, *Borneo J. Mar. Sci. Aquacult.*, **1** (2017), 71–74. https://doi.org/10.51200/bjomsa.v1i0.994
16. B. D. Schwartzkopf, S. A. Heppell, A feeding-ecology-based approach to evaluating nursery potential of estuaries for black rockfish, *Mar. Coastal Fish.*, **12** (2020), 124–141. https://doi.org/10.1002/mcf2.10115
17. C. Corinaldesi, S. Canensi, A. D. Anno, M. Tangherlini, I. D. Capua, S. Varrella, et al., Multiple impacts of microplastics can threaten marine habitat-forming species, *Commun. Biol.*, **4** (2021), 431. https://doi.org/10.1038/s42003-021-01961-1
18. C. Bertolini, I. Bernardini, D. Brigolin, V. Matozzo, M. Milan, R. Pastres, A bioenergetic model to address carbon sequestration potential of shellfish farming: example from *Ruditapes philippinarum* in the Venice lagoon, *ICES J. Mar. Sci.*, **78** (2021), 2082–2091. https://doi.org/10.1093/icesjms/fsab099

19. J. Guiet, *Environmental Impact on Fish Communities in The Global Ocean: A Mechanistic Modeling Approach*, 2016.
20. J. L. Deng, Control problems of grey systems, *Syst. Control Lett.*, **1** (1982), 288–294. https://doi.org/10.1016/S0167-6911(82)80025-X
21. D. Lei, K. Wu, L. Zhang, W. Li, Q. Liu, Neural ordinary differential grey model and its applications, *Expert Syst. Appl.*, **177** (2021), 114923. https://doi.org/10.1016/j.eswa.2021.114923
22. Y. Kang, S. Mao, Y. Zhang, Variable order fractional grey model and its application, *Appl. Math. Modell.*, **97** (2021), 619–635. https://doi.org/10.1016/j.apm.2021.03.059
23. W. Xie, M. Pang, W. Wu, C. Liu, C. X. Liu, *A Framework for General Conformable Fractional Grey System Models: A Physical Perspective and Its Actual Application*, 2021.
24. J. Jiang, T. Feng, C. Liu, An improved nonlinear grey bernoulli model based on the whale optimization algorithm and its application, *Math. Probl. Eng.*, **2021** (2021), 6691724. https://doi.org/10.1155/2021/6691724
25. L. Yu, X. Ma, W. Wu, X. Xiang, Y. Wang, B. Zeng, Application of a novel time -delayed power-driven grey model to forecast photovoltaic power generation in the Asia-pacific region, *Sustainable Energy Technol. Assess.*, **44** (2021), 100968. https://doi.org/10.1016/j.seta.2020.100968
26. Z. Xu, L. Liu, L. Wu, Forecasting the carbon dioxide emissions in 53 countries and regions using a non-equigap grey model, *Environ. Sci. Pollut. Res.*, **28** (2021), 15659–15672. https://doi.org/10.1007/s11356-020-11638-7
27. J. Wang, P. Du, Quarterly PM2.5 prediction using a novel seasonal grey model and its further application in health effects and economic loss assessment: evidences from Shanghai and Tianjin, China, *Nat. Hazards*, **107** (2021), 889–909. https://doi.org/10.1007/s11069-021-04614-y
28. Y. Cao, K. Yin, X. Li, C. Zhai, Forecasting CO_2 emissions from Chinese marine fleets using multivariable trend interaction grey model, *Appl. Soft Comput.*, **104** (2021), 107220. https://doi.org/10.1016/j.asoc.2021.107220
29. L. Tu, Y. Chen, An unequal adjacent grey forecasting air pollution urban model, *Appl. Math. Modell.*, **99** (2021), 260–275. https://doi.org/10.1016/j.apm.2021.06.025
30. S. Ding, R. Li, S. Wu, W. Zhou, Application of a novel structure-adaptative grey model with adjustable time power item for nuclear energy consumption forecasting, *Appl. Energy*, **298** (2021), 117114. https://doi.org/10.1016/j.apenergy.2021.117114
31. S. Ding, R. Lin, Z. Tao, A novel adaptive discrete grey model with time-varying parameters for long-term photovoltaic power generation forecasting, *Energy Convers. Manage.*, **227** (2021), 113644. https://doi.org/10.1016/j.enconman.2020.113644
32. S. Ding, R. Li, S. Wu, A novel composite forecasting framework by adaptive data preprocessing and optimized nonlinear grey bernoulli model for new energy vehicles sales, *Commun. Nonlinear Sci. Numer. Simul.*, **99** (2021), 105847. https://doi.org/10.1016/j.cnsns.2021.105847
33. M. Wang, W. Wang, L. Wu, Application of a new grey multivariate forecasting model in the forecasting of energy consumption in 7 regions of China, *Energy*, **243** (2022), 123024. https://doi.org/10.1016/j.energy.2021.123024

34. B. Zeng, H. Li, Prediction of coalbed methane production in China based on an optimized grey system model, *Energy Fuels*, **35** (2021), 4333−4344. https://doi.org/10.1021/acs.energyfuels.0c04195
35. B. Zeng, M. Zhou, X. Liu, Z. Zhang, Application of a new grey prediction model and grey average weakening buffer operator to forecast China's shale gas output, *Energy Rep.*, **6** (2020), 1608–1618. https://doi.org/10.1016/j.egyr.2020.05.021
36. Q. Tang, J. Zhang, J. Fang, Shellfish and seaweed mariculture increase atmospheric CO_2 absorption by coastal ecosystems, *Mar. Ecol. Prog. Ser.*, **424** (2011), 97–104. https://doi.org/10.3354/meps08979
37. B. E. Lapointe, M. M. Littler, D. S. Littler, A comparison of nutrient-limited productivity and physiological state in macroalgae from a caribbean barrier reef and mangrove ecosystem, *Aquat. Bot.*, **28** (1987), 243–255. https://doi.org/10.1016/0304-3770(87)90003-9
38. G. Rosenberg, T. A. Probyn, K. H. Mann, Nutrient uptake and growth kinetics in brown seaweeds: response to continuous and single additions of ammonium, *J. Exp. Mar. Biol. Ecol.*, **80** (1984), 125–146. https://doi.org/10.1016/0022-0981(84)90008-X
39. D. Xu, G. Bewnn, L. Xu, X. W. Zhang, X. Fan, W. T. Han, et al., Ocean acidification increases iodine accumulation in kelp-based coastal food webs, *Global Change Biol.*, **25** (2019), 629–639. https://doi.org/10.1111/gcb.14467
40. L. Wu, S. Liu, L. Yao, S. Yan, D. Liu, Grey system model with the fractional order accumulation, *Commun. Nonlinear Sci. Numer. Simul.*, **18** (2013), 1775–1785. https://doi.org/10.1016/j.cnsns.2012.11.017