The Carrying Capacity, Biomass Yields and Management Strategies of the Yellow Sea LME

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Outline

1. Carrying Capacity
2. Biomass Yields and Changing States
3. Management Strategies and Sustainability
4. Perspectives and Emerging Science
1. Carrying Capacity

- Carrying capacity is a concept related with population growth asymptote and ecosystem support;
- In reality, carrying capacity is dynamic.
1. Carrying Capacity (CC)

- Definition of CC:
  - Sharkey (1970): CC is defined as the weight of a single or mixed population that can be supported permanently on a given area;
  - Odum (1971): CC is applied to the population growth achieved at the asymptote in the logistic population growth equation;
  - PICES (1996): CC for a given population is considered to be the limiting size of that population that can be supported by an ecosystem over a period of time and under a given set of environment conditions.
1. Carrying Capacity (CC)

- In fact, CC depends on the changes of a number of factors, such as primary productivity, climate change, and trophic level.

For example: It has been estimated that in the central part of the Yellow Sea the primary production can produce as much as $10 \times 10^6$ t of carbon during the spring blooms, and contribute to the regional total annual primary production up to 32%. But, the spring blooms are the effected by a number of factors.
A example of the dynamics of primary productivity in spring bloom (Tang et al. (eds), 2013. Spring bloom processes and the ecosystem: the case study of the Yellow Sea. Deep-Sea Research II: 97, 1–116)

Picture cutline: **Background** is phytoplankton bloom on 4 April 2007

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**Fig. 1** Conceptual framework from the spring bloom study, illustrating the relationship of phytoplankton blooming with hydro-dynamics and supply of nutrients;

**Fig. 2** Time series of vertical profiles of sigma-t density (kg/m3) and fluorescence (Chl a, µg/l) at the station Z4;

**Fig. 3** MODIS image of dust storm during spring time cover the YS, 31 March 2007;

**Fig. 4** The major blooms causing species, a diatom *Skeletonema dohmi*;

**Fig. 5** Time series of vertical profiles of picoplankton;

**Fig. 6** The major grazers, copepod *Calanus sinicus*.
1. Carrying Capacity (CC)

- Application of CC in capture fisheries:
  \[ MSY = \frac{rk}{4} \]  (MSY will change with TL)

Figure 2.1: The results of a surplus production model in a mixed fishery in the Yellow Sea.
(From Tang, 1978, 1989)

Trophic level (TL) of important species declined obviously from 4.1 in 1959~60 to 3.4 in 1998~99, the Bohai Sea; from 3.7 in 1985~86 to 3.4 in 2000~01 (and 3.5 in 2013), the Yellow Sea.
1. Carrying Capacity (CC)

Application of CC in Aquaculture:
CCA will change with harvest strategy and mariculture mode.

Culture density (______) and CCA (-------) for scallops in Sungo Bay

Mariculture density and CCA in Sungo Bay:

- Blue Bar--culture density
- Red Bar--CCA
- CCA by area--
  - East: 12000-15000棵/1500m²
  - Central: 6000-7000棵/1500m²
  - West: 4000-5000棵/1500m².
2. Biomass Yields and Changing States

- Over the past half a century, the YSLME has changed greatly under the multiple stressors (including over-exploitation, climate change and eutrophication);
- Changing states of biomass yields have become a basic feature in the YSLME or in the coastal ocean ecosystems.
2. Biomass Yields and Changing States

Fisheries resources in the YSLME have been overfished since 1980. As a result, the commercially important long-lived, high trophic level, piscivorous bottom fish have been replaced by the low-valued shorted-lived, low trophic level, planktivorous pelagic fish. But, recent surveys indicate that the abundance of pelagic species, e.g. anchovy, is declining, while the biomass of demersal is increasing.

(Generalized history of the fisheries in the Yellow Sea, Tang 1993).
2. Biomass Yields and Changing States

- Changes in biomass yields by season in YSLME

(Based on survey data by R/V BeiDou of YSFRI)
2. Biomass Yields and Changing States

- Changes in biomass yields by category in YSLME

(Based on survey data by R/V BeiDou of YSFRI)
2. Biomass Yields and Changing States

- Changes in biomass yields in selected area of YSLME

(Based on survey data by R/V BeiDou of YSFRI)
2. Biomass Yields and Changing States

Changes in species composition in YSLME

(Based on survey data by R/V BeiDou of YSFRI)
2. Biomass Yields and Changing States

Changes in species compositions in YSLME

<table>
<thead>
<tr>
<th>Year</th>
<th>Top three dominant species</th>
<th>% accounted for total BY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>anchovy, flatfish, eelpout,</td>
<td>72</td>
</tr>
<tr>
<td>1998</td>
<td>anchovy, sand launce, small yellow croaker</td>
<td>72</td>
</tr>
<tr>
<td>2001</td>
<td>s- yellow croaker, anchovy, red-nose anchovy</td>
<td>48</td>
</tr>
<tr>
<td>2005</td>
<td>spotted velvafish, s- yellow croaker, half fin anchovy</td>
<td>54</td>
</tr>
<tr>
<td>2010</td>
<td>s- yellow croaker, yellow goosefish, mantis shrimp</td>
<td>44</td>
</tr>
<tr>
<td>2013</td>
<td>mantis shrimp, sand swimming crab, anchovy</td>
<td>47</td>
</tr>
</tbody>
</table>
2. Biomass Yields and Changing States

- **Control Mechanism**

  An analysis of inter-decadal variations of ecosystem production indicates that it is difficult to use any traditional theory (e.g. bottom-up, or top-down, or wasp-waist control) to directly and clearly explain the long-term variations of the productivity of different trophic levels in the coastal ocean ecosystems;

  An acceptable explanation is that the changes in the coastal ocean ecosystem may be a consequence of multifactorial controls. The multi-control mechanism may contribute to ecosystem complexity and uncertainty that are difficult to identify and manage.
3. Management Strategies and Sustainability

- When we face the impacts of multi-stressors and multi-control mechanisms, the best option is to develop an adaptive strategy for the practice of ecosystem-based management (EBM);
- Two main management strategies should be encouraged. One is to develop resource conservation-based capture fisheries, and the other is to develop environmentally friendly aquaculture (Tang 2014).
3. Management Strategies and Sustainability

- main measures for the development of resource conservation-based capture fisheries:
  - To close fishing season and reduce fisheries effort. China has initiated steps toward recovery by mandating 60-90 day closures to fishing in the Yellow Sea, East China Sea and South China Sea during summer months since 1995. Meanwhile, 30% of fishing boats have been reduced.

Season closed:
- June 16 to September 1 in the Bohai Sea;
- June 16 to September 1 in the Yellow Sea;
- June 16 to September 16 in the East China Sea;
- June 1 to August 1 in the South China Sea.
3. Management Strategies and Sustainability

- main measures for the development of resource conservation-based capture fisheries:
  - To promote stock enhancement program

Since 1984, the experimental release of penaeid shrimps in the Bohai Sea, the north Yellow Sea and the southern waters off the Shandong Peninsula has achieved remarkable social and economic benefits.

In 2006, the Chinese State Council promulgated a program of action on the conservation of living aquatic resources of China. This program has provided guidance for the conservation of living aquatic resources. Now, stock enhancement become a public activity for increasing marine food resources, and about 50 billion hatchlings of several species were put into the Chinese coastal waters from 2006 to 2010.
A example of enhancement practices for capture fisheries: Scallop released on bottom in northern part of YS LME
Officials from central and local government, diplomat from South Korea and scientists work together for stock enhancement, July 7, 2011, Weihai Shandong.
3. Management Strategies and Sustainability

- main measures for the development of resource conservation-based capture fisheries:
  - Artificial enhancement practices are an effective resource recovery strategy that should be expanded to a LME scale.
  - But, the recovery of ecosystem resources is a slow and complex process, so the development of resource conservation-based capture fisheries will be a long-term and arduous task.
3. Management Strategies and Sustainability

- Main measures for the development of environmentally friendly mariculture (EFM).

- One choice is to develop new mariculture model, e.g., integrated multi-trophic aquaculture (IMTA). Not only does IMTA provide more production but it also indirectly or directly reduces excess atmospheric CO₂ and nutrients, and increases the social acceptability of culturing systems.

(IMTA structure from Fang et al. 2009)
3. Management Strategies and Sustainability

- Science base of new multi-trophic mariculture model in the YSLME: I
- Trophodynamics studies showed that there is a negative relationship between ecological conversion efficiency and trophic level at the higher trophic levels.

![Graph showing relationship between ecological conversion efficiency and trophic level in the Yellow Sea ecosystem (Tang et al., 2007).](image)

- LH: rednose anchovy, sand lance, gizzard shad and finespot goby.
- HL: red eelbream, black porgy, tiger puffer, fat greenling and halfbeak.
- ?: black rockfish, chub mackerel.
Based on this new finding, harvest species at low trophic level may provide more production, and a new harvest strategy should be considered,
-- If we are concerned with large fish, A (red circle, high trophic level) will be selected-- top harvest strategy;
-- If we want to have more seafood, B (green circle, low trophic level) will be selected. In the case of China, B should be selected--non top harvest strategy).

So, IMTA will be a good choice.
Science base of new multi-trophic mariculture model in the YSLME: II

- Studies on biogeochemical cycle in mariculture system showed that shellfish and seaweed mariculture increase atmospheric CO$_2$ absorption by coastal ecosystems (Tang et al. 2011).
  - It is estimated that 3.79 ± 0.37 Mt C yr$^{-1}$ are being utilized, and 1.20 ± 0.11 Mt C yr$^{-1}$ were removed from the Chinese coastal ecosystem by harvesting from 1999 to 2008.
  - Cultivated shellfish and seaweeds can play an important role in carbon sequestration and "removal carbon sink", and will therefore contribute to improving the capacity of coastal ecosystems to absorb atmospheric CO$_2$; So, IMTA will be a good choice.
A example of scallop (Chlamys farreri) carbon budget in a culture system during a farming cycle (unit: mg C/ind./500 days)

Removal C by Harvest
3075 (~30%)

Shell 2070

Soft tissue 1005

Use C
10170

Ingestion 6030

DIC(HCO₃) 4140

Respiration 1040

Calcification 2070

Release C
3110 (~30%)

faeces & excretion

Biodeposit 3985 (~40%)

(adapted from Zhang in Tang et al. 2013)
3. Management Strategies and Sustainability

- Ecosystem services value of IMTA

  The value of food provision service and climate regulating service provided by the IMTA mode is much higher than in a monoculture.

Table 1 Service function in different mariculture modes in Sungo Bay (adapted from Liu et al., 2013)

<table>
<thead>
<tr>
<th>Mariculture mode</th>
<th>Value of food provision service (CNY/ha/yr)</th>
<th>Value of climate regulating service (CNY/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelp monoculture</td>
<td>49,219</td>
<td>4,859</td>
</tr>
<tr>
<td>Abalone monoculture</td>
<td>235,409</td>
<td>8,215</td>
</tr>
<tr>
<td>Abalone and kelp IMTA</td>
<td>325,553</td>
<td>13,591</td>
</tr>
<tr>
<td>Abalone, sea cucumber and kelp IMTA</td>
<td>483,918</td>
<td>13,833</td>
</tr>
</tbody>
</table>
4. Perspectives and Emerging Science

- Two main management strategies of marine food resources are practicable; IMTA is an adaptive, efficient, and sustainable way to respond to multiple stressors for coastal ocean ecosystems.

- For future development and better understanding of coastal ecosystems, it is necessary to further strengthen basic research. Moreover, studies on the functions and processes of carbon sink/source and the impact of ocean acidification and globe warming on ecosystem resources should be further examined.
A example of the Impact of ocean acidification on early embryonic development of the Pacific abalone

OA could prolong hatching time, delay embryonic development, increase mal-formation rate and reduce shell growth (Li JQ et al., 2013)
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Beautiful IMTA
Beautiful Future

Thank You!