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Spartina alterniflora Biomass Utilization and Benefit Assessment in China

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ABSTRACT

This study explores the utilization of *Spartina alterniflora* biomass and the development of innovative products derived from this invasive species. Initially introduced to China for coastal erosion control and wetland restoration, *S. alterniflora* has been harnessed for creating a bio-mineral liquid (BML) and various derivative products such as *Spartina* beverage, beer, sherbet powder, and capsules. These products offer significant health benefits and contribute to the local economy. The research evaluates the benefits of *S. alterniflora* biomass utilization using a comprehensive new methodology. This approach incorporates updated market values and advanced utilization techniques, providing a more accurate assessment of economic, ecological, and social benefits. The benefit calculation formula used in this study is:

$B = B_1 + B_2 + B_3$

Where:
$B_1 = W \times C_g \times P_n$, represents the value of *Spartina* extraction.
$B_2 = (F_1C_1 + F_2C_2 + F_3C_3 + F_4C_4) - 4/5\ B_1$, represents the value of *Spartina* series products.
$B_3 = R_u \times W(1 - C_g)(P_{r1} + P_{r2})$, represents the residue value.

The total benefit was calculated to be 18 111 000 RMB/hm^{2}yr (\$2 502 556/hm^{2}yr). This evaluation underscores the potential of *Spartina* biomass utilization as a sustainable ecological industry, balancing invasive species control with substantial economic returns.

Introduction

Spartina alterniflora is a perennial salt marsh grass native to the Atlantic and Gulf coasts of North America. The plant disperses by seeds and rhizome fragments, forming small tussocks and then covering the eventual elevation of intertidal habitats. It always primarily invades bare intertidal mudflats. *S. alternoflora* has been introduced throughout Europe, Australia, and Asia in efforts to prevent shoreline erosion (Maricle and Lee, 2002), to accelerate land formation, and to restore degraded wetlands from oil pollution (Lin and Mendelssohn, 1998) during the last centuries.

Recognized for its conspicuous effect of diminishing strong tide and accelerating sediment deposition, *S. alterniflora* was introduced into China by Nanjing University in 1979 (Chung, 2004). With artificial transplantation and natural dispersing, *S. alterniflora* is now distributed in nine of the 14 coastal provinces in East and South China. It reaches Zhuhai in the southwest (N22°17′, E113°33′) and Huludao in northeast (N38°56′, E121°35′), spanning from the tropics to the temperate zone. Now in the coastal region of China, *S. alterniflora* has expanded to around 55 468hm^2 (Zhang, D.H. et al., 2017).

Recently, worldwide debate about this species has arisen. On one hand, *S. alteriflora* is a competent pioneer and serves a series of functions in coastal ecosystems. However, its rapid spread on tidal lands has made it an invasive species and has drawn strong protest and objection (Li, B., et al., 2019).

Qin Pei Team (QPT) of Nanjing Univ. proposed a series of method to overcome *Spartina* invasion. The first is "Ecological Control" technology. In natural conditions no species has been found to substitute *S. alterniflora* in subtropical and temperate intertidal zones in China by modifying the microgeomorghic and hydrological regime of salt marsh, the natural vegetation succession of coastal wetland occurs according to the gradient change of elevation, tide strength and salinity in the habitat. This regime change resulted in rapid growth of the native *Phragmites* community and substitution for *S. alterniflora* (Qin, et al., 2019).

The second method uses the technology of QPT, which is "*Spartina* Biomass Utilization." Primarily, the above ground *S. alterniflora* biomass removed for invasion control is used as the feedstock for the extraction of a bio-mineral liquid (BML) and its series products, such as *Spartina* beverage, *Spartina* beer, *Spartina* sherbet powder, and *Spartina* capsule, which has been proposed to treat gout and boost immune function (Qin, 2019). Next, the residue left after extraction is used as a medium for mushroom cultivation, and for raising earthworms. Finally, the remaining residue becomes the main component of a microbe enriched organic fertilizer, which is then returned to the soil (Wang, et al., 2008; Wan, et al., 2009).

This paper attempts to assess the benefits of *Spartina alterniflora* utilization, according to the methods provided by QPT (Qin, et al., 1997).

Materials and Methods

Spartina alterniflora Biomass Utilization

From September to December each year, QPT harvests *Spartina* culms to produce BML because the culms contain much more nutrients and bioactive materials at that time. The simple procedure is used as follows: the culm's fragment is soaked in boiling water for 2 h, and the thin extract is concentrated to a chestnut brown liquid with special gravity of 1.25. This Spartina extract liquid is called Biomineral Liquid (BML) (Qin, et. al., 1998). BML could be used for a series of *Spartina* products, e.g., *Spartina* beverage, *Spartina* beer, *Spartina* sherbet powder, and *Spartina* capsule, etc.

The Value Calculation of *Spartina alterniflora* Biomass Utilization

Spartina Extraction Value Calculation

The equation for *Spartina* extraction value is

$$B_1 = W \times C_g \times P_n \qquad (1)$$

Where W is the total biomass of *Spartina* culm per hm^2 and per year, C_g is the coefficient of change from grass to BML, and P_n is the profit of BML.

Spartina Series Products Value Calculation

The equation for *Spartina* series products value is

$$B_2 = (F_1C_1 + F_2C_2 + F_3C_3 + F_4C_4) - 4/5B_1 \qquad (2)$$

Where F_1 is the part of BML used for *Spartina* beverage (BMW) production, F_2 is the part of BML used for *Spartina* beer production, F_3 is the part of BML used for *Spartina* sherbet powder production, F_4 is the part of BML used for *Spartina* capsule production, C_1 is the appreciation coefficient of beverage production, C_2 is the appreciation coefficient of beer production, C_3 is the appreciation coefficient of sherbet powder production, and C_4 is the appreciation coefficient of capsule production.

Spartina Extract Residue Value Calculation

The residue value equation is

$$B_3 = R_u \cdot W(1- Cg)\ (P_{r1}+P_{r2}) \quad (3)$$

Where R_u is the residue use ratio, P_{r1} is the net profit of the residue from mushroom, and P_{r2} is the net profit of the residue from fodder, and W, C_g are as in equation (1).

Results

Spartina alterniflora Biomass Utilization

The utilization of *Spartina alterniflora* biomass encompasses a series of structured processes, as delineated in the methodology section. Vast expanses of *Spartina alterniflora* plantations are strategically situated in the coastal wetland of Yanchen city, China, serving as the focal point of biomass extraction endeavors, as depicted in Figure 1. The harvesting phase typically occurs during September through December, ensuring optimal biomass yield and quality, as illustrated in Figure 2.

Following the harvest, the biomass undergoes meticulous handling procedures, including transportation to designated processing facilities, depicted in Figure 3. At these facilities, specialized extraction techniques are employed to obtain Biomineral Liquid from the harvested *Spartina alterniflora* culms, as shown in Figure 4. This Biomineral Liquid is the foundational element for producing a diverse range of derivative products, as shown in Figures 5, 6, 7 and 8. The grass residue is used, see Fig. 9. And the following showed 9 photographs all provided by QPT.

Figure 1. A vast area of *Spartina alterniflora* extraction Plantation in Yancheng, China.

Figure 2. Harvested *S. alterniflora* culms for production.

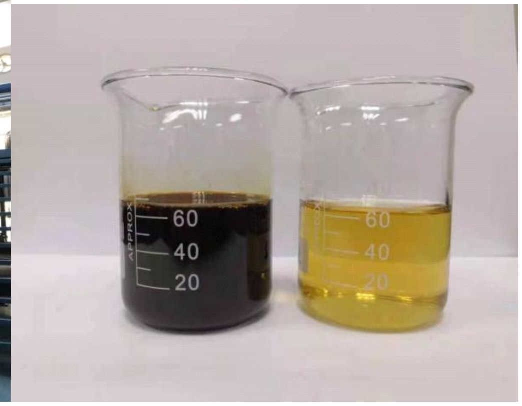

Figure 3. *S. alterniflora* extracted workshop Yancheng, China.

Figure 4. S. alterniflora extraction BML (L) and in its dilution (R) Biomineral Water.

Figure 5. *Spartina* beverage “BMW”.

Figure 6. *Spartina* Beer.

Figure 7. *Spartina* sherbet powder.

Figure 8. *Spartina* capsule.

Figure 9. The mushroom growing on *Spartina* extract residue.

The Value Calculation of *Spartina alterniflora* Biomass Utilization

Spartina Extraction Value Calculation

Using equation (1) and QPT's data (Qin, 1997), we can calculate the *Spartina* extraction value as follows:

B_1 = 30 000kg/hm^{2}yr × 0.1 × 50 RMB/kg = 150 000 RMB/hm^{2}yr

Comparing 1997's price of BML, now the price changes from 30 RMB/kg to 50 RMB/kg.

Spartina Series Products Value Calculation

Applying equation (2) and QPT's data (Qin, et al., 2019; Qin, 2019), we calculated *Spartina* series products value as follows:

B_2 = ((30 000 × 100) + (30 000 × 100) + (30 000 × 200) + (30 000 × 200) - 4/5 × 150 000RMB = 3 000 000 + 3 000 000 + 6 000 000 + 6 000 000 - 120 000 = 17 880 000 RMB/hm^{2}yr

Where F_1, F_2, F_3 and F_4 are 1/5 of B_1 respectively, C_1, C_2 are 100 respectively, C_3 and C_4 are 200 respectively, which are according to QPT's materials, of course, these coefficients will modify with *Spartina* industry development. And the last F, F5, used in other *Spartina* products.

Spartina Extract Residue Value Calculation

Utilizing equation (3) and QPT's data (Qin, et. al., 1997), we computed the *Spartina* extract residue value as follows:

B_3 = 0.5 × 30 000kg/ hm^{2}yr × (1 - 0.1) × (5+1) = 81 000RMB/hm^{2}yr

Thus, B = B_1 + B_2 + B_3 = 150 000 RMB/hm^{2}yr + 17 880 000 RMB/hm^{2}yr + 81 000 RMB/hm^{2}yr = 18 111 000 RMB/hm^{2}yr = $2 502 556/hm^{2}yr

Discussion

Spartina alterniflora Biomass Utilization Is a Hopeful Ecological Industry

Using biomass is a promising avenue for developing a sustainable ecological industry. By harnessing the natural resources provided by *Spartina*, innovative methods pioneered by the Qin Pei Team (QPT) of Nanjing University not only address the challenges posed by *Spartina* invasion but also offer a range of ecological and economic benefits.

Firstly, the utilization of *Spartina* biomass represents a proactive approach to mitigating the negative impacts of *Spartina* invasion. Rather than viewing *Spartina* as a solely problematic invasive species, this strategy acknowledges its presence and transforms it into a valuable resource. By harvesting and processing *Spartina* culms, not only is the spread of the invasive species controlled, but also the potential ecological disturbances caused by its unchecked proliferation are mitigated.

Moreover, the diverse range of products derived from *Spartina* biomass highlights its versatility and potential for economic growth. The production of bio-mineral liquid (BML) and its derivative products such as *Spartina* sherbet powder, capsules, and beer not only demonstrates the resourcefulness of utilizing natural materials but also opens new avenues for marketable goods. These products, with their unique health benefits and market appeal, have the potential to contribute to the growth of local economies, the total benefit so big and rare as \$347 783/hm^2yr, and create employment opportunities within the ecological industry sector.

Furthermore, the utilization of *Spartina* biomass aligns with broader sustainability goals by promoting circular economy principles. The integrated approach outlined by QPT, which involves the extraction of valuable compounds from *Spartina* culms followed by the utilization of residual biomass for mushroom cultivation, earthworm farming, and organic fertilizer production, exemplifies the efficient use of resources and waste minimization. This closed-loop system not only maximizes the value extracted from *Spartina* biomass but also reduces environmental impacts by minimizing waste generation.

Spartina *alterniflora* biomass utilization represents a promising ecological industry that combines ecological control concept of invasive species and biomass multilevel utilization which fits cleaner production principle. Although *Spartina alterniflora* biomass utilization technology stems from China, its ecological-economic and even social benefits have universal application, and other invasive districts for this reason of *Spartina*.

New Benefit Assessment of *S. alterniflora* Biomass Utilization

The innovative approach of utilizing *S. alterniflora* biomass presents a change in basic assumptions in coastal ecosystem management, offering a multifaceted array of benefits that warrant a thorough assessment.

Originally, QPT estimated the ecological-economic benefits of *S. alterniflora* plantation, including its natural and ecological uses, e.g., in accretion for reclamation, and especially seashore stabilization, as local people thought *Spartina* was a “special talisman” to resist typhoons. QPT’s estimation of these natural and ecological uses only covered the seashore stabilization and determined saved money to repair the shore bank by *S. alterniflora* plantation, as the natural ecological-economic benefit. This estimation significantly underestimated the ecological-economic benefit of *Spartina*, and QPT has not continued to assess the benefit of natural and ecological uses, so this paper does not pay attention to this estimation.

New benefit assessment of *S. alterniflora* biomass utilization focuses on the biomass utilization, in an effort to estimate the benefit of the extraction of *S. alterniflora* (BML) and its series products, including *Spartina* beverage, *Spartina* beer, *Spartina* sherbet powder, and *Spartina* capsule. Although the calculation equation of BML benefit is the same as the equation of QPT in1997, but P_n modifies, price of BML, now the price changes from 30 RMB/kg to 50 RMB/kg.

This paper seeks to estimate the benefit of 4 *Spartina* products, The equation for *Spartina* series products value is

$B_2 = (F_1C_1 + F_2C_2 + F_3C_3 + F_4C_4) - 4/5B_1$

Where F1, F2, F3, and F4 are the part of BML used for 4 Spartina products production, C1, C2, C3 and C4 are the appreciation coefficient of 4 Spartina products. According to research materials of QPT, this paper sets F_1, F_2, F_3 and F_4 are 1/5 of B_1 respectively, C_1, C_2 are 100 respectively, C_3 and C_4 are 200 respectively, and the last F, F5, used in other *Spartina* products.

Comparing 3 Benefit Assessment Methods of *Spartina alterniflora* Biomass Utilization

The evaluation of the benefits derived from *S. alterniflora* biomass utilization can be approached through various methodologies, each offering unique insights into the economic, ecological, and social dimensions of this innovative practice. Here, we compare three distinct benefit assessment methods to elucidate their strengths and limitations:

One method involves estimating the monetary value of *Spartina* marsh using an equation proposed by Odum (Odum, E.P et al., 1973; Odum, E.P. et al., 1972) which converts energy into currency. According to this approach, the dollar value of *Spartina* can be calculated using the equation $B = W \times Q_w / Q_m$, where W represents the total biomass of *Spartina* culm, Q_w denotes the coefficient of energy/biomass conversion, and Q_m signifies the coefficient of energy/money conversion. Utilizing specified values for these parameters, the resulting dollar value of *Spartina* is determined as $12 150 per hectare per year (See Table 1).

Another method proposed by Qin et al. offers a practical approach to assessing *Spartina alterniflora*'s benefits. It involves a more intricate calculation that considers various factors such as the proportion of C_g, R_u, as equation 1 and equation 3 mentioned of Materials and methods in this paper, the coefficient of resisting typhoon (T_i), the coefficient of environment factors (E_f), the coefficient of plant fee (F_p), the coefficient of saving the repairing expense (M_s), and residue use coefficients (P_{r1}, P_{r2}) also see Table 1. The equation for this method, $W \times C_g \times P_n + (T_i \times E_f - F_p)M_s + R_u \times W(1 - Cg)(P_{r1} + P_{r2})$, yields a calculated value of $20 058 per hectare per year.

Additionally, this paper introduces another practical method for evaluating *Spartina alterniflora*'s benefits. By reference of QPT's method this paper's method continues to use some coefficients such as C_g, R_u, P_{r1}, P_{r2}, but adds a series coefficient, C_1, C_2, C_3, C_4, according to *Spartina* industry development. The equation for this approach as: $W \times C_g \times P_n + (F_1C_1 + F_2C_2 + F_3C_3 + F_4C_4) - 4/5B_1 + R_u \times W(1 - Cg)(P_{r1} + P_{r2})$, results in a calculated value, and the total benefit is $2 502 556/$hm^2$yr (See Table 1).

That means the bigger the degree of development, the higher the benefit of biomass utilization via comparing 3 benefit assessment methods of *Spartina alterniflora* biomass utilizationor. For example, the new benefit of *Spartina alterniflora* biomass utilization is 200 times higher than Odum's benefit, and 100 times higher than Qin's benefit.

It evident that the development and utilization of *Spartina* hinges on its ecological engineering, which pertains to the manipulation of environmental systems by humans using minimal supplementary energy to regulate systems primarily driven by natural sources.

Each benefit assessment method offers valuable insights into various aspects of *Spartina* biomass utilization, highlighting its multifaceted nature. The economic value assessment method provides a clear understanding of the financial returns associated with *Spartina* biomass utilization, making it particularly useful for investors and policymakers interested in the economic viability of this practice. However, it may overlook the broader ecological and social benefits, potentially underestimating the overall value of *Spartina* biomass utilization.

Table 1. 3 benefit assessment methods of *Spartina alterniflora* biomass utilization

Methods	Approaches	Calculation equations	Key coefficient	Value （$/ hm^2.year）
Odums	Theoretical	$W \times Q_w / Q_m$	Q_w , Q_m	12 150
Qin, et al	Practical	$W \times C_g \times P_n + (T_i \times E_f - F_p)M_s + R_u \times W(1- C_g)(P_{r1} + P_{r2})$	C_g, T_i, E_f, F_p, R_u, P_{r1}, P_{r2}	20 058
This Paper	Practical	$W \times C_g \times P_n + (F_1C_1 + F_2C_2 + F_3C_3 + F_4C_4) - 4/5B_1 + R_u \times W(1- C_g)(P_{r1} + P_{r2})$	C_g, C_1, C_2, C_3, C_4, Ru, P_{r1}, P_{r2}	2 502 556

Conclusions

1. Resource utilization is the best way to mitigate the invasion of *Spartina alterniflora*. Timely harvesting effectively halts the maturation and dispersal of seeds, thereby controlling the disordered expansion of *Spartina alterniflora* and contributing to the enhancement of biodiversity in affected ecosystems. This approach not only addresses the challenges posed by *Spartina* invasion but also provides a sustainable solution that aligns with principles of ecological stewardship.

2. *Spartina* resource utilization emerges as a unique and promising industry with significant potential for economic, ecological, and social benefits. By harnessing the natural resources offered by *Spartina*, innovative utilization methods pave the way for the development of a sustainable ecological industry. The diverse range of products derived from *Spartina* biomass underscores its versatility and marketability, offering opportunities for economic growth and job creation in coastal communities.

3. This article's assessment of the *Spartina* industry draws on the essence of previous methods while also introducing innovative approaches. By synthesizing and building upon existing methodologies, this assessment provides a comprehensive evaluation of *Spartina alterniflora* biomass utilization which follows *Spartina* industry progress. The incorporation of novel techniques and considerations enhances the robustness and applicability of the assessment, contributing to a deeper understanding of the economic, ecological, and social dimensions of *Spartina* resource utilization.

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