

Growth Strategy of Seagrass *Thalassia hemprichii* in Xincun Bay near Hainan Island of China

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Abstract: A compilation of data on biomass and growth allowed an examination of the intraspecific plasticity in *Thalassia hemprichii* which played key roles to develop site-specific growth strategies for this species in Xincun Bay. The results showed the difference in rhizome elongation rates which explained most of the variation of biomass and growth within species. The seagrass *T. hemprichii* in Xincun Bay adjusted its vertical and horizontal rhizome elongation rates alternatively in response to light level and temperature changes, resulting in the variation of shoot densities and above biomass in return. The vertical and horizontal rhizomes elongated at rates of 2.38 and 24.4 cm yr⁻¹ in summer while 1.87 and 29.2 cm yr⁻¹ in winter respectively. The shoot density ranged from 822 to 941 shoots m⁻² with a peak in summer and a trough in winter which was similar to that of biomass. The growth strategy enabled *T. hemprichii* to minimize the negative effects of desiccation in summer as well as light reduction in winter.

Keywords: *Thalassia hemprichii*, intraspecific variation, rhizome elongation rates

Seagrasses are valuable coastal resources characterized by a relative taxonomic and architectural uniformity and represented by few species (Den Hartog 1970; Stevenson 1988). Yet, the biomass and turnover rates of different seagrass species differ by orders of magnitude. Attempts to explain differences in seagrass biomass and production have focused primarily on the influence of habitat conditions, particularly on temperature, light and nutrient availability (Short 1987; Duarte 1991). Duarte and Marbà have succeeded in using an extensive compilation of data on architecture and growth of different seagrass species to examine the implications of differences in module size to account for differences in productivity among seagrass species (Duarte 1991; Marbà and Duarte 1998). Duarte (1991) founded a close scaling of the size of leaves, shoots, and fruits to rhizome diameter, as well as strong relationships between shoot size and the dynamics (e.g. turnover rate, plastochrone interval, and longevity). Although much (between 40% and 173%) of the variability of seagrass horizontal rhizome and clonal growth programmes is species-specific and largely (21% to 63% of the variance) associated with differences in size among species, seagrasses also show important intraspecific variability (Marbà and Duarte 1998). The considerable intraspecific plasticity in seagrass module size suggests that it may have an important adaptive value, therefore, an important component of the capacity of seagrasses to cope with changes

and heterogeneity in the environment. In turn, the plasticity of seagrass modules may also respond to the availability of resources, reducing the construction cost when resources are scarce (Hemminga and Duarte 2000). In another word, the intraspecific plasticity has formed the base for seagrass populations to develop site-specific growth strategies which play a key role in the population survive and expansion (Vermaat et al. 1997).

Seagrass *Thalassia hemprichii* is among the most widely-distributed seagrass species in an Indo-Pacific flora, dominating in many mixed meadows (den Hartog 1970; Brouns 1987; Vermaat et al. 1995). The biomass and growth of *T. hemprichii* have been widely researched in Southeast Asia, especially in the Philippines (Agawin et al. 2001; Brouns 1985; Estacion and Fortes 1998; Erftemeijer and Herman 1994; Lanyon and Marsh 1995), southern Taiwan of China (Lin and Shao 1998), Kenya (Uku and Bjork 2005), Mozambique (Paula et al. 2001) and Arabian sea (Jagtap 1998). However, no study on the site-specific growth strategy of this species was reported. Here, we conducted a study to examine these growth characteristics for *T. hemprichii*. We also compiled all the growth and biomass data from the available literature as points of comparison. Our study area near Hainan Island is located at the intersection of the tropical southern Indo-Pacific flora. The published data combined with our results will allow us to better examine the site-specific growth strategy of this species, a factor important in the disturbance and recovery dynamics of this species and therefore the management.

1 Materials and methods

1.1 Study sites

The present study was performed at Xincun Bay (18°24'34"N - 18°24'42"N, 109°57'42"E - 109°57'58"E) located in south of Hainan province, China (Fig. 1). Xincun Bay (22.6 km² water surface) is a nearly closed lagoon with only one narrow entrance in the southwest, by which it exchanges water with South China sea. According to the surveys performed in 2002, a mixed seagrass meadow with an area of about 200 ha inhabits in the southern shallow waters of Xincun Bay (Huang et al. 2006). All the seagrass species presented at this meadow were *Thalassia hemprichii*, *Enhalus acoroides*, *Halophilas ovalis*, *Halodule uninervis* and *Cymodocea rotundata*. *Enhalus acoroides* was dominant species followed by *Thalassia hemprichii*.

1.2 Environmental parameters

We measured seawater surface temperature daily with a seawater surface thermometer. Salinity was determined by a hand-held refractometer. Measurements of photosynthetically active radiation (PAR) at the seagrass canopy level were collected during 1 - 3 h at noon (daily maximum of incoming of irradiance) with a LI-193SA spherical quantum sensor. The content of nitrate, nitrite, ammonium and phosphate of the water samples were then determined with methods described by Parson et al. (1984).

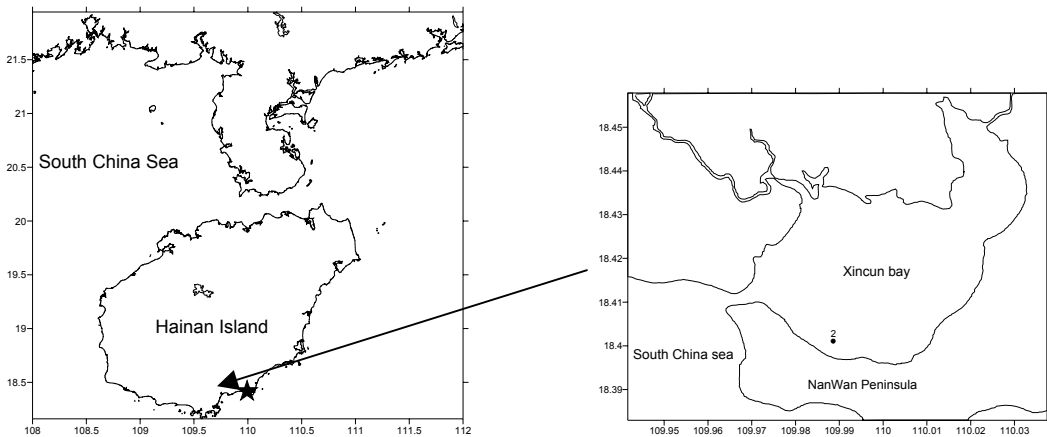


Fig. 1 Map of the Xincun Bay, showing the sampling sites

1.3 Biomass and growth of *T. hemprichii* in Xincun Bay

From November 2004 to January 2006, sampling of plant biomass was made seasonally within an area of 50 m × 50 m (central point was at 18°24'3.6"N 109°59'20.4"E) during low tide periods with a depth between 0.3 and 1.0 m. Sampling was conducted within intertidal monotypic stand of *T. hemprichii* which was exposed into air during low tide periods. Biomass samples were collected randomly using an aluminium frame (surface area 0.0 625 m²) by 6 replicates. All the plant material within the frame was harvested and transported on ice to a laboratory and stored in a refrigerator at 4 °C. At the laboratory, samples were rinsed with tap water and divided into different plant parts (leaves, rhizomes, roots). Epiphytes were removed by careful scraping of the leaves. The plant were dried at 80 °C for 24 hours and weighed.

Leaf growth was measured in Jul 2005 and Jan 2006 respectively, corresponding to the highest and lowest level of the PAR and seawater surface temperature during a year. Leaf growth was obtained by the hole punch methods described by Dennison (1990) and Zieman (1974). A minimum of 50 shoots were punched and have been harvested after 10 days. We estimated the leaf plastochrone interval (leaf PI) by the methods described by Brouns (1985).

Vertical rhizome elongation was calculated by regressing the length of vertical rhizomes against shoot age. The slope of the regression equation represented the vertical elongation rate. The growth rate of the horizontal rhizome may be obtained by dividing the length of the rhizome between 2 consecutive shoots by the difference in the ages of the 2 shoots (Duarte et al. 1994). The production of roots in the vertical shoots can be estimated by regressing the number of roots formed against shoot ages, and the production of roots in the horizontal rhizomes can be calculated as the product of the root numbers per unit rhizome biomass and the production of horizontal rhizomes (Duarte et al. 1994).

Shoot age was estimated as the product of the total number of leaves produced during the shoot life-span (i.e. number of standing leaves plus number of leaf scars on the vertical rhizome supporting the

shoot) multiplied by the leaf PI (in days).

1.4 Intraspecific plasticity in biomass and growth of *T. hemprichii*

We compiled from the published literature (Tab. 1) available data on leaf weight, aboveground biomass, leaves numbers per shoot, leaf PI, rhizome elongation rate and shoot density of *T. hemprichii*. We consider individual seagrass stands as the units of this study. We use the coefficient of variation (CV) to quantify the intraspecific variability of biomass and growth of *T. hemprichii* (Marbà and Duarte 1998; Hemminga 2000).

Tab. 1 Sources of data on 1(1) leaves numbers per shoot, (2) leaf productivity, (3) leaf PI, (4) aboveground biomass, (5) vertical rhizome elongation rate, (6) horizontal rhizome elongation rate and (7) shoot density.

Source	Site	Variables	Number of stands examined	Habitats
Vermaat et al.(1995)	The Philippines	7	3	reef flat
Agawin et al.(2001)	The Philippines	2	1	lagoon
Rollon et al. (2001)	The Philippines	5	1	reef flat
Gacia et al.(2003)	The Philippines	2	5	reef flat
Uku and Bjork (2005)	Kenya	3	4	lagoon
Jagtap (1998)	India	3	7	lagoon
Huang et al. (2006)	China	2	2	lagoon
This study	China	8	1	lagoon

2 Results

2.1 Environmental parameters of the study areas

The PAR level revealed a distinctly unimodal seasonality with a maximum of $1\,861 \pm 69 \mu\text{mol /s m}^{-2}$ in Jul 2005 and a minimum of $1\,438 \pm 42 \mu\text{mol /s m}^{-2}$ in Jan 2006. The sea surface temperature showed a similar seasonal variation coincided with the PAR during the sampling periods. The water column at study sites were of low level of nutrients with mean concentrations of $3.1 \mu\text{mol/L}$ dissolved inorganic nitrogen (a sum of nitrate, nitrite and ammonium) and $0.28 \mu\text{mol/L}$ phosphate, respectively.

2.2 Biomass and growth of *T. hemprichii* in Xincun Bay

The biomass of *T. hemprichii* varied seasonally (Fig. 2a). The whole plant biomass (a sum of dry weight of leaves, rhizomes and roots) ranged from $284.3 \pm 84.2 \text{ g DWm}^{-2}$ in autumn to $409.6 \pm 75.5 \text{ g DWm}^{-2}$ in winter. The biomass of rhizomes and roots increased from spring to autumn and decreased sharply during winter while the opposite pattern was observed in the variation of leaves biomass. Leaves biomass ranged from a minimum of 59.2 g DWm^{-2} in summer to a maximum of 115.2 g DWm^{-2} in winter. The root shoot ratio also varied from 0.24 in summer to 0.33 in winter with an average of 0.30 (Fig. 1b).

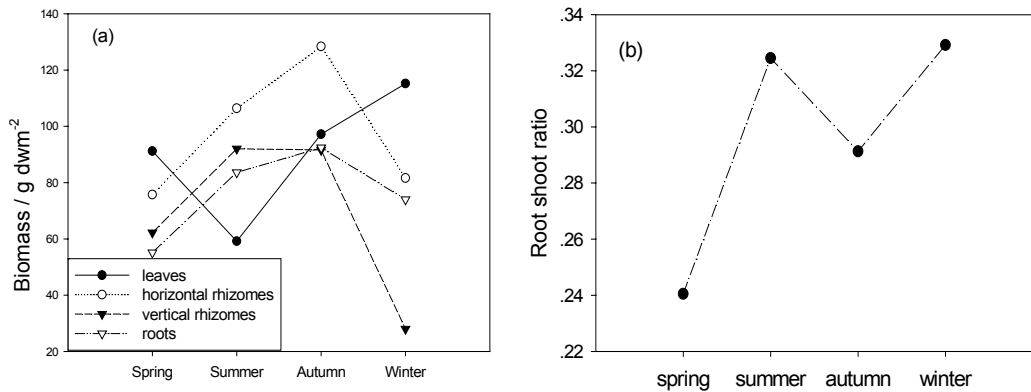


Fig. 2 Temporal variation of (a) the biomass of leaves, rhizomes and roots, (b) root shoot ratio of *T. hemprichii* in Xincun Bay

The leaf plastochrone interval was 10.6 days. The leaf elongation rates were 2.8 ± 1.3 mm leaf¹/d and 2.6 ± 1.6 mm leaf¹/d in summer and winter respectively. The shoot density ranged from 822 to 941 shoots m⁻² with an average of 884 shoots m⁻². The maximum of shoot density was recorded in summer and the minimum in winter.

The vertical rhizome growth was significantly correlated with shoot age, which allowed the calculation of vertical rhizome elongation rates. The vertical rhizome growth rates were 2.38 cm/yr in summer ($R^2 = 0.59$, $p < 0.01$, $n = 97$) and 1.87 cm/yr in winter ($R^2 = 0.64$, $p < 0.01$, $n = 148$). The horizontal rhizome growth rates reached the values of 24.40 and 29.20 cm/yr in summer and winter respectively. As we can see, the seasonality of the vertical rhizomes was quite different from that of horizontal ones. The vertical rhizome extended at a 27.3% greater rate in summer than in winter, while the horizontal rhizome elongation rate in winter was 20% greater than that in summer.

The formation rate of roots on horizontal rhizomes (19.6 roots yr⁻¹) was almost one times greater than that on vertical rhizomes (10.8 roots yr⁻¹), which indicated faster lateral growth of horizontal rhizomes than vertical ones in winter.

The shoot age structure was characterized by a high abundance of shoots younger than 1.7 yr old followed by an exponential decline in shoot abundance for older shoots. Most of the shoot aged from 20 PIs (212 d) to 60 PIs (636 d).

2.3 Intraspecific plasticity in biomass and growth of *T. hemprichii*

The variation of shoot density ranked the first within specie variation of *T. hemprichii* followed by rhizome elongation rates. The minimal variation occurred in the leaf plastochrone interval followed by leaves number per shoot, showing much more conservative traits within this species (Tab. 2). The shoot densities of the populations inhabited in lagoons were significantly greater than those in reef flats ($P < 0.01$) while no obvious differences are found between the aboveground biomass ($P > 0.05$), suggesting the

greater shoot size of reef flat populations than lagoon ones.

Tab. 2 Data on leaves number per shoot (LN), leaf productivity (LP, in g DW m⁻² / day), aboveground biomass (AB, in g DW m⁻²), leaf plastochrone interval (PI, in days), vertical rhizome elongation rate (VE, in cm shoot⁻¹ / yr), horizontal rhizome elongation rate (HE, in cm/yr) and shoot density (Den, in shoots m⁻²)

Site	LN	LP	AB	PI	VE	HE	Den
Philippine	3.9	4.14	250.2	10.9	3	20.6	548
		4.08					533
			148	9.19	2.14	56	1 358
			167.9		1.65	36	1 853
				10.9			335
				10.9			65
				11			325
Kenya	4.05	5.4					653
	3.8	2.85					733
India	3		25.3				300
	3						270
	3						300
	4		109.2				270
	4		258.3				1 300
	4		231.6				1 000
	3		34.2				150
China		4.07					1 508
		2.76					1 024
	4.6	2.02	154	10.6	2.12	26.8	884
Within species CV / %	15.42	35.21	56.20	7.35	25.26	44.35	72.61

3 Discussion

3.1 Extent of intraspecific plasticity in biomass and growth of *T. hemprichii*

The bio-geographic researches of *T. hemprichii* indicated a relative wide distribution of this species. As showed in Tab. 2, a considerable extent of intraspecific plasticity in biomass and growth of *T. hemprichii* was observed. This was one of the most important reasons for which it dominated in many seagrasses meadows. In fact, the plasticity in the architecture of seagrasses was an important component of their capacity to adapt to disturbance or resource heterogeneity. The horizontal rhizomes have an exploratory capacity, being responsible for the extension of the clone into new areas and recruitment of new shoots, while vertical rhizomes have the capacity to use resources, deploying leaves and roots at the same position to use the local resources (Hemminga and Duarte 2000). The diameter of seagrass

rhizomes are most conservative traits within individual species (Duarte 1991, Marbà and Duarte 1998). So the intraspecific plasticity in biomass and growth of *T. hemprichii* was mainly attributed to the within-species variation of rhizome elongations. For instance, the populations in reef flats developed less dense but greater size of shoots responding to greater water dynamical power than those in lagoons.

3.2 Site-specific growth strategy of *T. hemprichii* in Xincun bay

The leaf and vertical rhizomes grew vertically while the horizontal rhizomes occupied the sediments by lateral elongation and branching. In general, these two aspects of the seagrass growth compete for resources and respond to the disturbances directly. In summer, most of the leaves biomass lost caused by desiccation and the herbivorous fishes, resulting in the leaves grew at a higher rate in order to recover as soon as possible. Although the gross leaf productivity was enhanced, the respiration rates of leaf segments might be unnaturally high due to high temperature and wound effects (Hemminga and Duarte 2000). As a result, the net leaf productivity was even lower than that in winter (1.85 and 2.80 mg DW shoot⁻¹/d, respectively). So the elongation of horizontal rhizomes was restrained by the reduced material flux from leaves to horizontal rhizomes and roots. And shoot density reached a maximal value of 941 shoots m⁻² in summer. On the contrary, the light intensity and temperature decreased in winter. The vertical growth of *T. hemprichii* reduced and more material was transported and stored in horizontal rhizomes and roots indicated by the increase of root shoot ratio from spring to winter (Fig. 2b). The lateral growth was strengthened which caused the shoot density decreased in return to avoid the shading effects. The courses discussed above can be illustrated as Fig. 3.

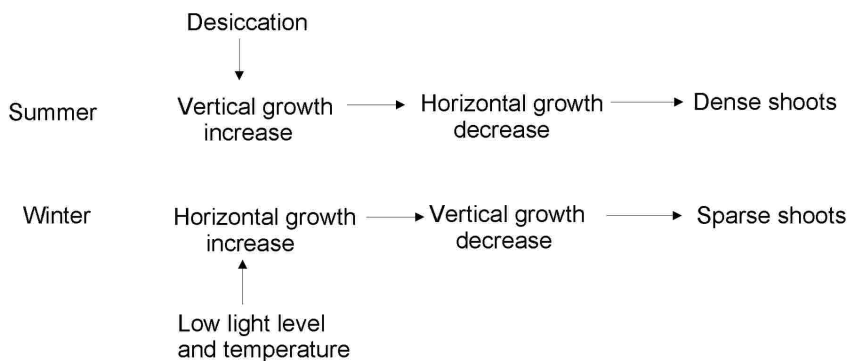


Fig. 3 Courses regulating the growth and biomass of *T. hemprichii*

The average and the maximum shoot ages of *T. hemprichii* in Xincun Bay were smaller than those reported in previous studies carried out in the Philippines (453 and 1 455 days, respectively), so did the horizontal and vertical rhizome elongation rates. This suggests the population in Xincun Bay was younger and more sensitive to disturbances than did those in the Philippines. As a result, it would recover more slowly after disturbances which emphasized the important of protecting the rhizomes in the efforts to retain the seagrasses meadow in this lagoon. And the activities endangering the growth of rhizomes (e.g. digging and raking shells, fishing by benthic trawling, Huang et al. 2006) should be forbidden as soon as

possible.

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References

- [1] Agawin NSR, Duarte CM, Fortes MD, et al. Temporal changes in the abundance, leaf growth and photosynthesis of three co-occurring Philippine seagrasses [J]. *J. Exp. Mar. Biol. Ecol.* 2001, 260: 217 - 239.
- [2] Brouns JJWM. A comparison of the annual production and biomass in three monospecific stands of the seagrass *Thalassia hemprichii* (Ehrenb) [J]. *Achers. Aquat. Bot.* 1985, 23: 149 - 175.
- [3] Brouns JJWM. Growth patterns of some Indo-West-Pacific seagrasses [J]. *Aquat. Bot.* 1987, 28: 39 - 61.
- [4] Duarte CM. Allometric scaling of seagrass form and productivity [J]. *Mar. Ecol. Prog.* 1991, Ser.77: 289 - 300.
- [5] Duarte CM, Marbà N, Agawin NSR, et al. Reconstruction of seagrass dynamics: age determinations and associated tools for the seagrass ecologist [J]. *Mar. Ecol. Prog.* 1994, Ser. 107: 195 - 209.
- [6] Den Hartog C. *The seagrasses of the world* [M]. Amsterdam, Netherland: North Holland Publishing House, 1970.
- [7] Dennison WC. Leaf production. In: Phillips RC and McRoy CP, eds. *Monographs on Oceanographic Methodology 9: Seagrass Research Methods* [J]. UNESCO, Paris. 1990, 77 - 79.
- [8] Erftemeijer PLA, Herman PMJ. Seasonal changes in environmental variables, biomass, production and nutrient contents in two contrasting tropical intertidal seagrass beds in South Sulawesi Indonesia [J]. *Oecologia.* 1994, 99: 45 - 59.
- [9] Estacion JS, Fortes MD. Growth rates and primary production of *Enhalus acoroides* L.f. Royle and its epiphytes [J]. *Aquat. Bot.* 1998, 29: 347 - 356.
- [10] Huang Xiao-ping, Huang Liang-min, Li Ying-hong, et al. Main seagrass beds and threats to their habitats in the coastal sea of South China [J]. *Chinese Science Bulletin* 51(Supp.II), 2006, 136 - 142.
- [11] Hemminga MA, Duarte CM. *Seagrass Ecology* [M]. Cambridge, UK: Cambridge University Press, 2000.
- [12] Jagtap TG. Structure of major seagrass beds from three coral reef atolls of Lakshadweep, Arabian Sea, India [J]. *Aquat. Bot.* 1998, 60: 397 - 408.
- [13] Lanyon JM, Marsh H. Temporal changes in the abundance of some tropical intertidal seagrasses in North Queensland [J]. *Aquat. Bot.* 1995, 49: 217 - 237.
- [14] Lin Hsing-Juh, Shao Kwang-Tsao. Temporal changes in the abundance and growth of intertidal *Thalassia hemprichii* seagrass beds in southern Taiwan [J]. *Bot. Bull. Acad. Sin.* 1998, 39: 191 - 198.
- [15] Marbà N, Duarte CM. Rhizome elongation and seagrass clonal growth [J]. *Mar. Ecol. Prog.* 1998, Ser.174: 269 -

280.

- [16] Parson TR, Maita Y, Lalli CM. A manual of chemical and biological methods for seawater analysis [M]. Oxford UK: Pergamon Press, 1984.
- [17] Paula J, Fidalgo e Costa P, Martins A, et al. Patterns of Abundance of Seagrasses and Associated Infaunal Communities at Inhaca Island, Mozambique [J]. Estuarine, Coastal and Shelf Sci. 2001, 53: 307 - 318.
- [18] Rollon RN, Cayabyab NN, Fortes MD. Vegetative dynamics and sexual reproduction of monospecific *Thalassia hemprichii* meadows in the Kalayaan Island Group [J]. Aquat. Bot. 2001, 71: 239 - 246
- [19] Stapel J, Manuntun R, Hemminga MA. Biomass loss and nutrient redistribution in an Indonesian *Thalassia hemprichii* seagrass bed following seasonal low tide exposure during daylight [J]. Mar. Ecol. Prog. 1996, Ser. 134: 251 - 262.
- [20] Stevenson JC. Comparative ecology of submerged grass beds in freshwater, estuarine, and marine environment. Limnol [J]. Oceanogr. 1988, 33: 867 - 893.
- [21] Short FT. Effects of sediment nutrients on eelgrass: literature review and mesocosms experiment [J]. Aquat. Bot. 1987, 27: 41 - 57.
- [22] Uku J, Bjork M. Productivity aspects of three tropical seagrass species in areas of different nutrient levels in Kenya [J]. Estuarine, Coastal Shelf Sci. 2005, 63: 407 - 420.
- [23] Vermaat JE, Agawin NSR, Duarte CM, et al. Meadow maintenance, growth and productivity of a mixed Philippine seagrass bed [J]. Mar. Ecol. Prog. 1995, Ser. 124: 215 - 225.
- [24] Vermaat JE, Agawin NSR, Fortes MD, et al. The capacity of seagrasses to survive increased turbidity and siltation: the significance of growth form and light use [J]. *Ambio* 1997, 26(8): 491 - 496.
- [25] Zieman JC. Methods for the study of the growth and production of turtle grass [J]. *Thalassia testudinum konig*. *Aquaculture* 4, 1974, 139 - 143.

新村湾海龟草 (*Thalassia hemprichii*) 的生长策略研究

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摘要: 海草的种内差异是它在特定环境中形成生长策略的关键因素。本研究通过将现场实测数据和文献记录进行类比以探讨新村湾海龟草 (*Thalassia hemprichii*) 的生长策略。研究表明海龟草地下茎伸长速率的差异可以解释该海草生物量和生长的大部分种内差异; 新村湾海龟草垂直地下茎和水平地下茎的伸长速率在夏季分别为 2.38 cm/yr 和 24.4 cm/yr, 在冬季分别为 1.87 cm/yr 和 29.2 cm/yr。海龟草茎枝密度的变化范围是 822 shoots m⁻² 至 941 shoots m⁻², 最大值出现在夏季而最小值出现在冬季, 生物量的季节变化与此类似。新村湾海龟草通过交替调节垂直地下茎和水平地下茎的伸长速率以适应光照强度和温度的季节变化, 从而导致茎枝密度和地上生物量的相应变化。通过这样的生长策略, 海龟草可以把夏季干旱和冬季光照强度下降对其生长造成的消极影响降低到最小程度。

关键词: 海龟草 (*Thalassia hemprichii*), 种内差异, 地下茎伸长速率