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Seasonality of epiphytic development of the hydroid *Obelia geniculata* on cultivated *Saccharina japonica* (Laminariaceae, Phaeophyta) in Korea

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Abstract The occurrence of encrusting colonies of the hydroid *Obelia geniculata* on farmed *Saccharina japonica* was examined between December 2007 and July 2008 at a *Saccharina* farm at Wando on the southwestern coast of Korea. The growth stages of *S. japonica* can be divided into two phases: an active growth phase from February to the end of May and a decay phase from June to July. There was a significant increase in the level of incrustation by colonies on fronds (measured as the percentage of fronds with encrusting colonies) between February and July ($p<0.05$). The encrusting colonies occurred first on the upper part of the frond in February and progressed to the basal part in July. The abundance of encrusting colonies in relation to the growth phase on farms over time was limited by the harvest of the seaweed crop at the end of the cultivation period in July. The stipes and holdfasts of fronds showed no signs of infestation at any time during the cultivation period. The extent of the infestation appeared to be related to a combination of factors. These could be reduced physiological activity and subsequent tissue aging that occurred simultaneously in the sporophytic life phase of *Saccharina* frond, and a rapid increase in reproduction and growth of *O. geniculata* coinciding with rising seawater temperature.

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Keywords Cultivation · Encrusting colony · Hydroid · *Obelia geniculata* · *Saccharina japonica*

Introduction

Seaweed cultivation is a major industry in many countries of the Asia-Pacific region, in particular Japan, Korea, and China (Morita et al. 2003). In Korea, Dasima [*Saccharina japonica* (Areschoug) C.E.Lane, C.Mayes, Druehl & G.W. Saunders] cultivation was largely developed, promoted, and industrialized in the 1970s. The production continuous to increase and 241,322 tons wet weight were harvested in 2010 (MIFAFF 2011). Recently, an abalone industry has been successfully developed in Korea, making use of the stable production of seaweed. The increasing demand for this seaweed has led to a substantial increase in the area being used for *S. japonica* farming in Korea. *S. japonica* production in Korea now accounts for about 26% of total Korean seaweed production. In the last two decades, *S. japonica* farms have suffered greatly from infestation by the epiphytic hydroid *Obelia geniculata* (L., 1758). The infestation is characterized by the appearance of numerous small colonies on the thallus of the alga. A kelp plant infested by hydroids is called "Hige-kombu" or "Ke-hae-kombu" that means "hairy *Saccharina*". Fronds with *O. geniculata* epiphytes are considered unsuitable for human consumption. Although consumption of raw or dried *Saccharina* encrusted by hydroid colonies has not resulted in outbreaks of food-borne disease, the presence of encrusting colonies in *Saccharina* products has been implicated in degradation of taste and quality of dried *Saccharina*, infested fronds cannot therefore command a good price in the market.

Epiphytic infestation of *Saccharina* is not a new phenomenon and has been known exist since the dawn of

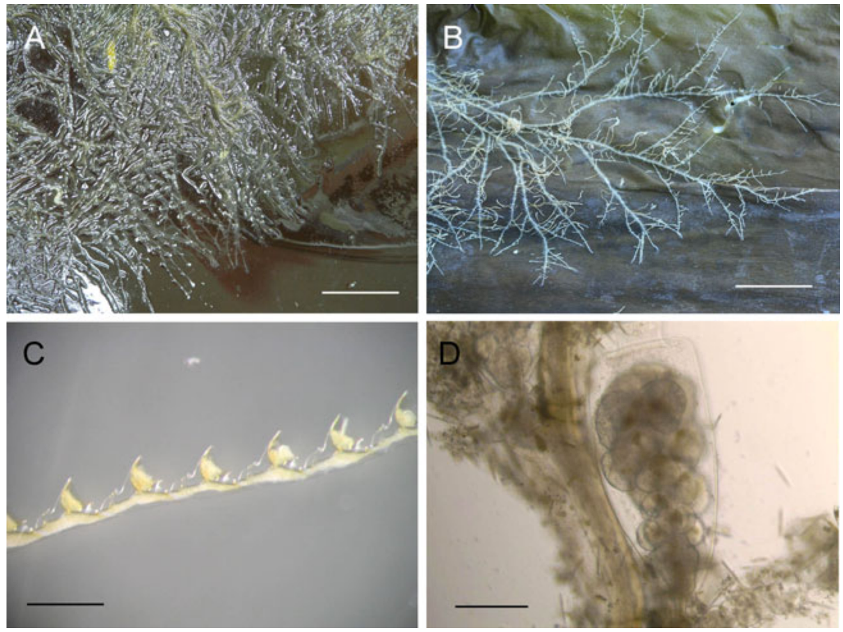


Fig. 1 Encrusting colonies of *Obelia geniculata* on cultured *Saccharina japonica*. **a** On a fresh *S. japonica* thallus. **b** On a dried *S. japonica* thallus. **c** A filament of *O. geniculata*. **d** Medusa buds of *O. geniculata*. *Scale bars* are 1 cm (**a**–**b**), 200 μm (**c**), and 100 μm (**d**)

farming practices in Korea (Hasegawa 1976; Kang and Ko 1977; Kawashima 1984). However, little is known of the causative agents, seasonality, or the physiological factors within the seaweeds that result in outbreaks (Slobodov and Marfenin 2004; Fraschetti et al. 2006). The causative agent of "Hige-kombu" was first reported in Asia by Tokida and Yama (1960) as hydrozoa that were first identified from *S. japonica* farms in Hakodate, Hokkaido, Japan. A similar infestation and occurrence of the same epiphyte was later noted by Chang and Chung (1971) in the *Laminaria religiosa* Miyabe beds along the east coast of Korea. Hasegawa (1962) reported that the epiphyte invasion were colonial hydroids such as *O. geniculata* and *Plumularia filicaulis*, and Kang and Ko (1977) reported that encrusting by *O. geniculata* was most abundant on farmed *S. japonica* at the end of the cultivation period.

In order to reduce the economic impact of epiphytic infestation, farmers harvest *S. japonica* before it has become heavily infested with hydrozoa. The objective of this study is to describe the occurrence of epiphytic hydrozoa during the different developmental stages of *S. japonica* on a seaweed farm. The results from this study will enable farmers to predict the optimal time for harvesting thalli before an outbreak of the encrusting epiphyte in *S. japonica* farms.

Materials and methods

The research was conducted on a *Saccharina japonica* farm at Wando in the southwestern coast of Korea (34°18′53.57″ N, 126°39′42.47″ E). This region in Korea is the most popular area for *S. japonica* cultivation but also includes

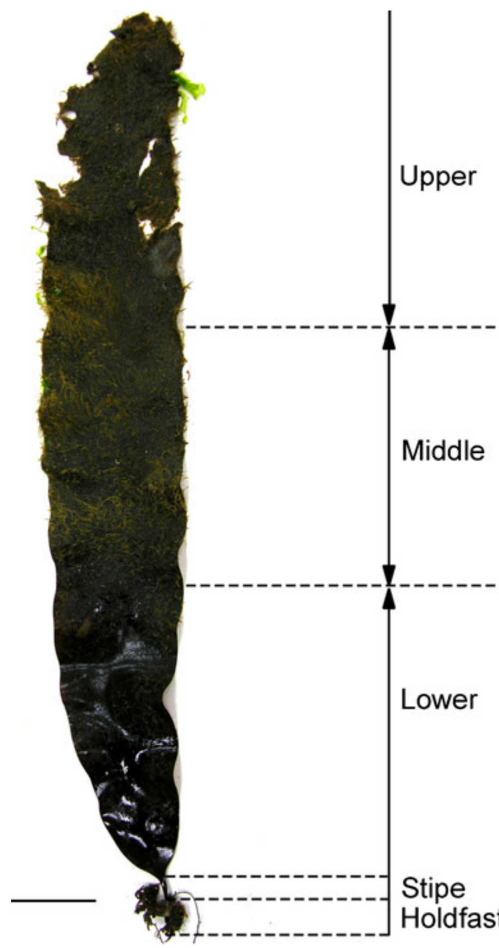


Fig. 2 Sporophyte of *Saccharina japonica*. Indicated regions of the frond (upper, middle, and lower) were divided into regions (upper, middle, and lower) for analysis on the occurrence of encrusting colonies of *Obelia geniculata*. *Scale bar* is 10 cm

farms for other commercially important algae such as *Porphyra* spp., *Undaria pinnatifida*, *Hizikia fusiformis*, *Sargassum fulvellum*, *Enteromorpha* spp., and *Capsosiphon fulvescens*.

Environmental factors, such as water temperature and salinity, were measured by a logging multi-parameter probe (YSI-85, YSI Co. USA) and current velocity was measured by a flow meter (BFM001, Valeport Ltd., UK) at the experimental site.

Cultivation of *Laminaria*

A seed rope (about 2 mm in diameter) with zoospores attached was introduced from Wando Prefecture, a native area for *S. japonica*. In December 2007, the seed rope with young (1 cm long, 10 days post-nursery culture) *S. japonica* sporophytes was cut into about 4-cm lengths and inserted at about 15-cm intervals in a culture rope that was 100 m long and about 1.5 cm in diameter. Culture ropes were suspended horizontally at about 1–2 m in depth at the experimental site. In January 2008, the rope was thinned to obtain a density of about 20 individuals per meter (Sohn and Kain 1989). The harvested fronds attain about 2,500 kg wet weight per 100 m of culture rope and *Saccharina* farms generally contain around 20 culture ropes per hectare.

Algal samples

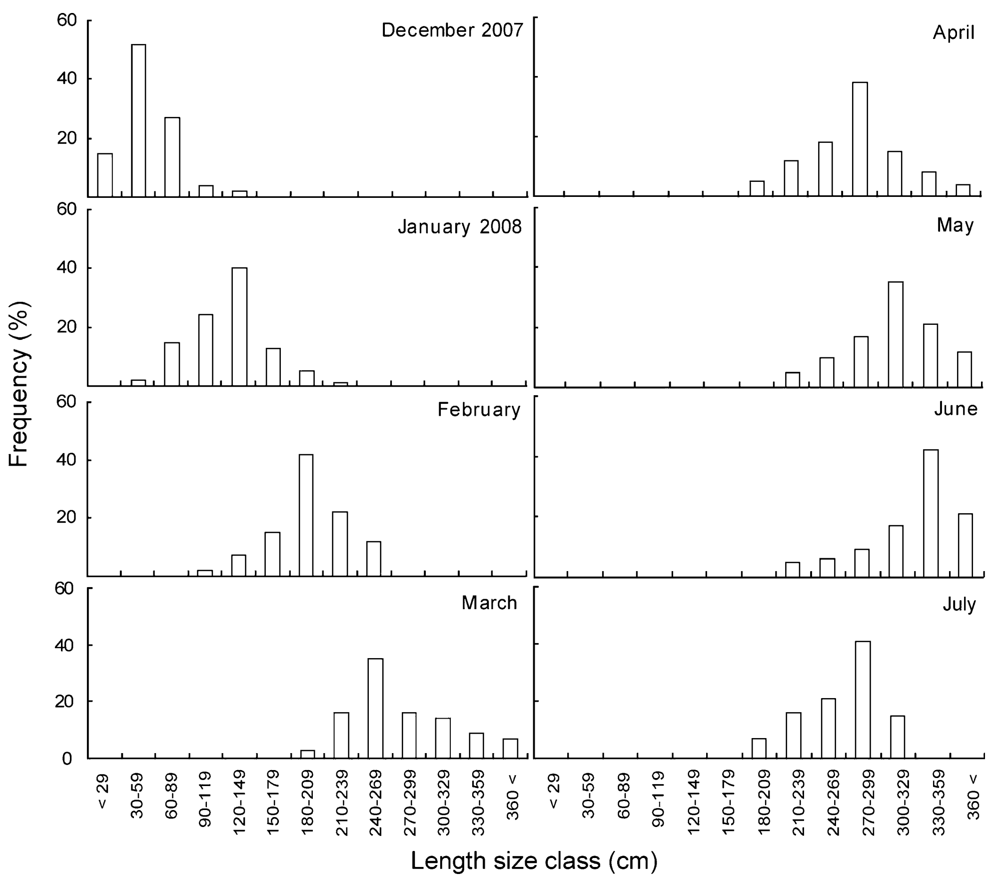
Each month between December 2007 and July 2008, samples of *S. japonica* were collected from the experimental site. This period encompassed both rapid growth and senescence phases of the kelp. Each month, 5 m of culture rope bearing about 100 individual plants was sampled. Total length (from apex to holdfast) of the thalli was measured, and the number of hydroid colonies on each of the sporophytes was counted and the diameter of the colonies measured using calipers. Sporophytes were classed either as mature or young. Mature sporophytes were defined as those greater than 150 cm in length, possessing reproductive sori. Young sporophytes were vegetative thalli less than 150 cm in length.

Obelia colonies

Examples of the encrusting hydroid *O. geniculata* on *S. japonica* from the experimental site are shown in Fig. 1. The structure of the hydroid colony has been described by Slobodov and Marfenin (2004). The occurrence of *Obelia* on sporophytes was measured as the percentage of thalli colonized as follows:

$$\text{No. of thalli with colonies} \times 100/\text{total inspected thalli}(n = 100)$$

Fig. 3 Length frequency of *Saccharina japonica* sampled between December 2007 and July 2008



The total area of the colonies on each frond was calculated from the average area of each colony (calculated from its mean diameter) multiplied by the number of colonies per frond. The fronds were divided equally into thirds to define upper, middle, and lower regions (Fig. 2). The lower part of the thallus was further divided into three subparts: lower, between basal top of the incision and stipe, and holdfast. Differences in the occurrence of hydroids on the upper, middle, and lower parts of each thallus were quantified for each of the affected thalli. The mean diameter of colonies was calculated based on the diameter of colonies from 50 portions randomly selected from each sporophyte (n=100).

Data analyses

The occurrence of encrusting colonies was expressed as a percentage of plants with colonies in each of four replicates of 25 plants. One-way ANOVAs were used to test for significant differences in the mean diameters of colonies on the kelp thalli between sampling dates. When an ANOVA revealed significant differences ($p<0.05$), *a posteriori* Fisher's LSD test was applied to determine where significant differences occurred among pair-wise months.

Results

Environmental conditions Water temperature at the farm site decreased from 10°C in early December to a minimum of 7°C in the middle of February, and increased again to 20°C in early July. Salinity at 1-m depth at the research site ranged from 30 to 33 psu. Variation in salinity was due to the input of fresh water from nearby rivers and land runoff. The mean current velocity at the site was 0.5 m s^{-1}.

Growth of S. japonica Length frequency analysis of *S. japonica* (Fig. 3) indicated the mean lengths of the population sample increased from 35±5 cm in December to 346±37 cm in June. In July, the mean length of the population was 310±42 cm, a decrease compared to the June sample. Sorus formation was first observed in May (ca. 10% of plants) and gradually increased to a maximum

Table 1 Monthly infection rates and average area of encrusting colonies of *Obelia geniculata* on cultured *Saccharina japonica*

Date	Infection rate of encrusting colonies (%)	% Infection in each section of the plant (%)		Area of encrusting colonies (cm^2)
December 2007–January 2008	0	U	0	0
		M	0	
		L	0	
		S & H	0	
February	6±1.2	U	100	0.6±0.2 a
		M	0	
		L	0	
		S & H	0	
March	15±3.4	U	100	28.7±2.7 b
		M	0	
		L	0	
		S & H	0	
April	26±3.5	U	95±3.2	43.7±3.2 c
		M	5±2.7	
		L	0	
		S & H	0	
May	72±9.3	U	85±1.7	98.8±12.5 c
		M	13±2.6	
		L	2±3.2	
		S & H	0	
June	97±5.4	U	65±3.4	216.5±32.6 c
		M	31±6.3	
		L	4±2.2	
		S & H	0	
July	97±5.6	U	63±2.5	480.4±54.7 c
		M	25±2.1	
		L	12±1.4	
		S & H	0	

Algal samples were collected monthly between December 2007 and July 2008. Values are mean±SD, n=250. Values (mean±SD) in same column having different superscripts are significantly different ($p<0.05$)

Plant sections: *U* upper part of frond, *M* middle part of frond, *L* lower part of frond, *S & H* stipe and holdfast (ca. 90% of plants) in July. Few young non-reproductive sporophytes were observed (ca. 10% of plants) in July, and the mature plants had signs of increasing erosion from their apices in July.

Obelia colonies Colonies were first observed on the fronds in February 2008 and they persisted throughout the experimental period. Early in colonization, small brown spots appear on the apical part of thallus blade, and subsequently these colonies spread over the blades with colony density reaching its maximum by the end of July. Colonies typically ranged from 0.5 to 12 cm along the length of their main axis and appeared either as localized irregularities or in a row (Fig. 1). The algal color at the periphery of the encrusting colonies was darker brown than the normal cells in the uncolonized parts of the thallus. The number of colonies observed on each frond and the percentage of fronds with encrusting colonies increased as algae aged with the frond infection increasing to 6% in February and to 97% by June and July (Table 1). The total average area of colonies on each thallus ranged from 0.6 cm^2 in February to 480.5 cm^2 in July 2008 (Table 1, one-way ANOVA, $p<0.05$). This result indicates that the incidence and extent of encrusting colonies on *Saccharina* were significantly greater in the late culture period than in the early culture period.

Encrusting colonies occurred most frequently on the upper parts of the fronds (Fig. 4a) and the frequency of encrusting colonies increased over time (Fig. 4b). In February, encrusting colonies were only found on the upper part of the thallus, but by April the colonies were present in the middle part of the thallus in 5% of infested plants. By July, the colonies also spread to the lower part of the frond in 12% of the infested plants (Table 1). Colonies were never observed on the stipe or holdfast of any thallus.

Discussion

Obelia geniculata has a worldwide distribution (Slbodov and Marfenin 2004). Colonies have been reported in shallow waters from areas such as Australia (Watson 1992), Mediterranean Sea (Boero and Bouillon 1993), North Atlantic (Whittick 1983), and the East Sea of Korea (Song et al. 1995). Since the first report of colonial hydroids infecting *S. japonica* cultivation areas in Korea by Kang and Ko (1977), studies have focused on the biology of the hydroid rather than its direct impact on algal production (Rho 1977; Choe and Kim 1988; Lim et al. 1992). Traditionally, the cultivation period for *S. japonica* spanned the period from December to July, with harvest of thalli occurring between March and July. Recently, the harvest season has been shortened from March to May, so as to avoid the period when the most severe infection by the hydroid occurs.

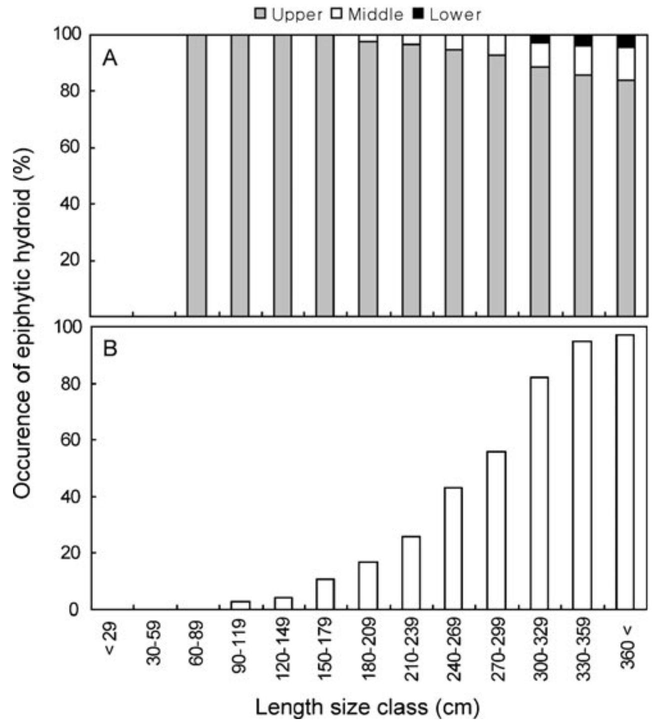


Fig. 4 Length frequency and location of encrusting colonies of *Obelia geniculata* on cultured *Saccharina japonica*. **a** Occurrence of hydroid colonies from upper, middle, and lower part of fronds. **b** Occurrence colonies on cultured *Saccharina japonica* against length size class of fronds

Our growth trials indicated that the maximum growth of *S. japonica*, in terms of increase in biomass, occurs during the period between June and July (Fig. 5) and, therefore, reducing the harvest period leads to a decrease in production from the farms. We estimate that the potential loss in harvest biomass resulting from harvesting plants early to avoid the hydroid cover is one third of total biomass (ca. 15 t wet wt. ha^{-1}) in the region (Fig. 5).

The maximum cover by hydroid colonies on fronds of *S. japonica* occurs at the end of the cultivation period. This

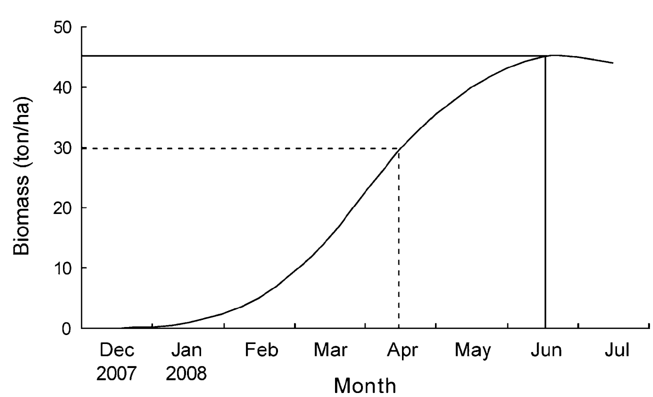


Fig. 5 Estimated biomass of *Saccharina japonica* during a culture period. The *solid line* is the normal harvest amount and the *dotted line* is the early harvest due to the occurrence of *Obelia*

coincides with a period when the frond tissue is becoming reproductive, softening, and starting to decay (Sanbonsuga 1984; Suzuki et al. 2006; Mairh et al. 1991; Matsuoka et al. 1991; Nakawaki et al. 2001). In addition, the higher water temperature at the end of *Saccharina* cultivation period has been linked to increased reproductive output in *Obelia*, resulting in an increased number of colonies developing on *S. japonica* thalli (Kang and Ko 1977).

The incidence of colonies was significantly lower on the middle and lower parts of the thalli than the upper parts. The colonies on the apical part of the fronds are enlarged and coalesce as the colonies expand. This process accelerates decay at the distal ends of the fronds and, if the cover by colonies becomes sufficiently abundant, the weakened frond will be fragmented with concomitant loss of biomass. As the algae age, the colonization by *Obelia* progressed from the tip of the plant toward the basal section. The lower part of the thallus was further divided into three subparts: lower, between basal top of the incision and stipe, and holdfast. In those subparts, the highest occurrence of colonies was observed on the section between the basal top of the incision and stipe. Colonies were never observed on the stipe or holdfast. More irregular-shaped and larger colonies were observed on the blade than on the other areas of the plant. The reason for this is unclear but could be attributed to the larger area available for colonization by hydroids on this part of the plant.

The color abnormalities observed in the algal tissues are similar to those reported by Slobodov and Marfenin (2004) and are attributable to the host plant's reaction to the presence of the hydroids. The colonies on the thallus of *S. japonica* were used by *O. geniculata* as a place in which to germinate frustules. Frustules remain on the wide and flat mucous-covered blades of the alga for a long time, and even if washed off, they adhere to adjacent blades (Boero et al. 2007). The occurrence of colonies would appear to be most active in young, rapidly growing tissue and hence it may also promote gradients in epiphyte distribution as occurs in *Saccharina* species (Russell 1983a, b). It is thus possible for particular host–epiphyte associations to arise in nature through interactive effects such as these (Russell and Veltkamp 1984). This biological characteristic of *O. geniculata* helps to explain its ability to be retained within seaweed farms and infect successive crops.

Panteleeva (1999) found that development of medusa gonads in *O. geniculata* requires water temperatures over 15°C, and those colonies of *O. geniculata* occurred only in shallow subtidal waters (0.5 to 7 m depth). Thus, it may be possible to reduce infestation of *S. japonica* thalli by cultivating this species in areas where water temperature is less than 15°C or at depths in excess of 7 m during the last periods of main cultivation. Another control strategy considered may be to encourage the growth of hydroid-eating predators, such as those described by Lambert (1991) to reduce colony growth on farms. However, the best strategy to reduce epiphyte outbreaks may be through improved farming practices for *Saccharina* including epiphyte-free seedlings and improved maintenance and cleaning of the *Saccharina* lines between crops.

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