

Water flow and sediment in *Enhalus acoroides* and other seagrass beds in the Andaman Sea, off Khao Bae Na, Thailand

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»» Received: 20 January 2004; Accepted: 5 March 2004

Abstract—To examine influences of tropical seagrass on marine physical environments, water flow and the sedimentation rate were measured in seagrass beds in the Andaman Sea, off Khao Bae Na, Trang Province, Thailand, in December 1998. Vertical profiles of water flow inside the seagrass beds and a sand bed were investigated using gypsum balls. Water flow inside beds of *Enhalus acoroides* (L.f.) Royle, which has large blades, was much smaller than that inside beds of *Thalassia hemprichii* (Ehrenb.) Aschers. and *Halophila ovalis* (R.Br.) Hook. f., which have small blades, or in the sand bed. The sedimentation rate measured with sediment traps inside the *E. acoroides* beds was greater than that inside the *T. hemprichii* beds at each station. The percentage of mud in the sediments inside an *E. acoroides* patch was higher than that outside it at the same station. Negatively proportional to water flow, the phi median diameters of sediments in the *Enhalus* beds were greater than those in the sand (unvegetated area) or *Thalassia* beds at the same station. These facts suggest that the vertical reduction in water flow depends on differences in the formation of seagrass meadows, and the sedimentation rate and sediment composition are influenced by the retardation of the water flow by the seagrass meadows.

Key words: water flow, plaster ball, seagrass, sediment, sedimentation, *Enhalus acoroides*, *Halophila ovalis*, *Thalassia hemprichii*, Andaman Sea, Thailand

Introduction

Seagrass beds act as nursery grounds for larvae and feeding sites for marine animals. They therefore play an important role for marine organisms in the tropical marine littoral ecosystem, which consists of three major subsystems: mangrove swamps, seagrass beds, and coral reefs. Although seagrass beds are also essential for the sustainable development of fisheries in the tropical littoral system, there are not enough studies on how to conserve and restore them (Fortes 1996). Along the southwest Thai coast, seagrass beds are broadly distributed in the Andaman Sea (Lewmanomont et al. 1996). Endangered species, such as the *Dugong dugong* (e.g., Nakaoka et al. 2000) and sea turtles (e.g., Aragon 2000), graze on seagrasses. To protect these species, it is necessary to conserve seagrass beds. Therefore, an understanding of seagrass ecosystems is essential for the conservation of the tropical marine littoral ecosystem along this coast.

Water flow is an important environmental factor influenc-

ing seagrass. Conversely, seagrass beds retard water flow by increasing drag (Gambi et al. 1990; Komatsu 1996). Water flow influences the fauna and flora inside seagrass beds (e.g., Scipione and Fresi 1984). To understand the seagrass ecosystem, knowledge of the interaction between seagrass beds and water flow is essential (Fonseca et al. 1983). The mean speed of flow around seagrass beds can be an important index of the environment, as it is related to the distribution of seagrass and the organisms living there, the substrata within the beds, and plant photosynthesis.

It is difficult to measure the water motion in seagrass beds in shallow water. Propeller-type current meters do not work smoothly for long period because the seagrass leaves usually become entangled with the current meter within one or two days. Hot-film sensors attached to seagrass blades (Koch 1994) and small electromagnetic-type current meters (e.g., Ackerman and Okubo 1993) are good for measuring water flow, but they are too expensive to use simultaneously at many depths and stations. To solve these problems, several

methods for measuring water flow have been devised using gypsum balls (e.g., Muus 1968; Doty 1971; Peticrew and Kalff 1991). These methods are based on the strong positive linear relationship between the dissolution rate of gypsum and a steady flow under constant conditions of water temperature and salinity, as reported by James and Lupton (1978). Komatsu and Kawai (1992) developed a new simple calibration method using the balls that Muus (1968) made from a mixture of plaster of Paris and distilled water.

Sediments are very important for animals living in a coastal ecosystem. Seagrass beds may influence the sedimentation rate and sediment distribution by retarding the water flow (Komatsu and Yamano 2000). Although we have been studying the capacity of seagrass or seaweed beds to create their own environment (Komatsu 1996; Komatsu and Murakami 1994), we have not previously reported the influence of seagrass beds on sedimentation rates and sediment distribution, or the differences in the sedimentation environment between seagrass species. Sedimentation is one of the most important environmental factors controlling this ecosystem.

This study examined the influence of seagrass beds on water flow and its dependence on seagrass species in the Andaman Sea, in Trang Province, Thailand. Moreover, we examined whether seagrass beds influence the sedimentation rate and sediment distribution in a field survey of the seagrass beds.

Materials and Methods

Study site

Field experiments were conducted in seagrass beds between Muk Island and Koh Bae Na in the Andaman Sea, Trang Province, Thailand (7°22'N, 99°18'E to 7°24'N, 99°21'E) (Fig. 1). The primary reason for selecting this location was the presence of large seagrass beds of different species and blade lengths. Four stations were established in representative areas with seagrass beds of each species with varying species composition and blade lengths. These features made it possible to compare water flow under different seagrass distributions *in situ*.

Methods

A pipe with attached gypsum balls was fixed to the bottom (Fig. 2) to measure water flow at depths of 0, 0.1, 0.2, 0.3, 0.4, and 0.5 m above the bottom at Stas. A2, C2, and D2, and at 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, and 0.9 m above the bottom at Sta. B2 (Fig. 1). Blades within 30 cm of a gypsum ball were removed in order to exclude the influence of local turbulence on the rate of gypsum dissolution. The gypsum balls

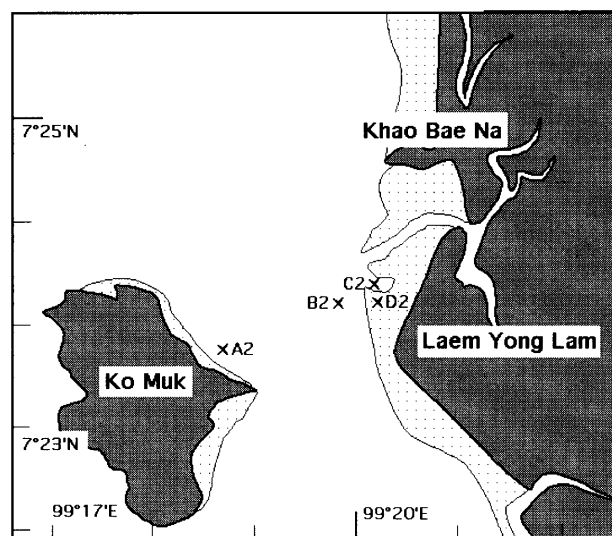


Fig. 1. Map showing the study site in the Andaman Sea off Khao Bae Na Point, in Trang Province, Thailand. The x's show the stations.

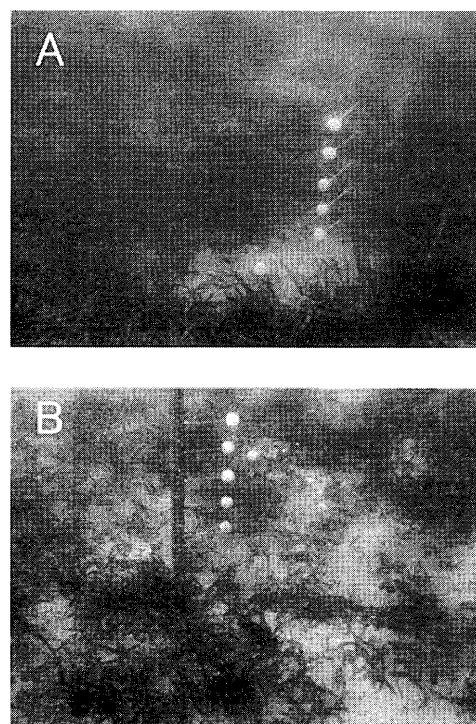


Fig. 2. Photographs of the apparatus used to measure water flow in *Enhalus* (A) and *Thalassia* (B) beds at Sta. A2.

were immersed for 50 h, which is equivalent to four times the semi-diurnal tidal period, between 2 and 4 December 1998. The wet weight of the gypsum balls was measured just before and after the experiment. The loss of wet weight was converted into the speed causing the equivalent loss in a tank filled with fresh water using the method of Komatsu and

Kawai (1992).

Sediment traps (diameter: 7.9 cm, depth: 8.2 cm) were set on the bottom in seagrass beds at Stas. A2, B2, C2, and D2 for 50 h from 2 to 4 December 1998. Unfortunately, the traps at Stas. B2 and D2 disappeared before they were retrieved. The materials obtained from the other traps were filtered using a glass fiber filter (GFF) and weighed after drying for two days at 60°C.

Sediments from the bottom surface were collected inside patches of *Thalassia hemprichii* (Ehrenberg) Ascherson and *Enhalus acoroides* (L.f.) Royle and in a sand bed at Sta. A, and inside and outside a patch of *E. acoroides* at Sta. B2. The particles were classified into six groups by dry sieving:

<0.063, 0.063–0.25, 0.5–0.25, 0.5–1, 1–2, and >2 mm. The dry weight of each sediment size was determined. A percentage of each group was used to calculate the phi median diameter, Md_{ϕ} .

To compare the aboveground parts of different seagrass species, divers made observations at Stas. A2, B2, C2, and D2 after the gypsum balls had been retrieved. *Enhalus acoroides* and *Thalassia hemprichii* were distributed at Stas. A2 and C2. In addition, *Halophila ovalis* (R. Brown) Hooker F. was found with them at Sta. D2. Hereafter, the terms *Enhalus*, *Thalassia*, and *Halophila* are used instead of the entire binomial name for simplicity. *Enhalus* was distributed at four stations. At Sta. B2, which had the deepest bottom, the *Enhalus* blades

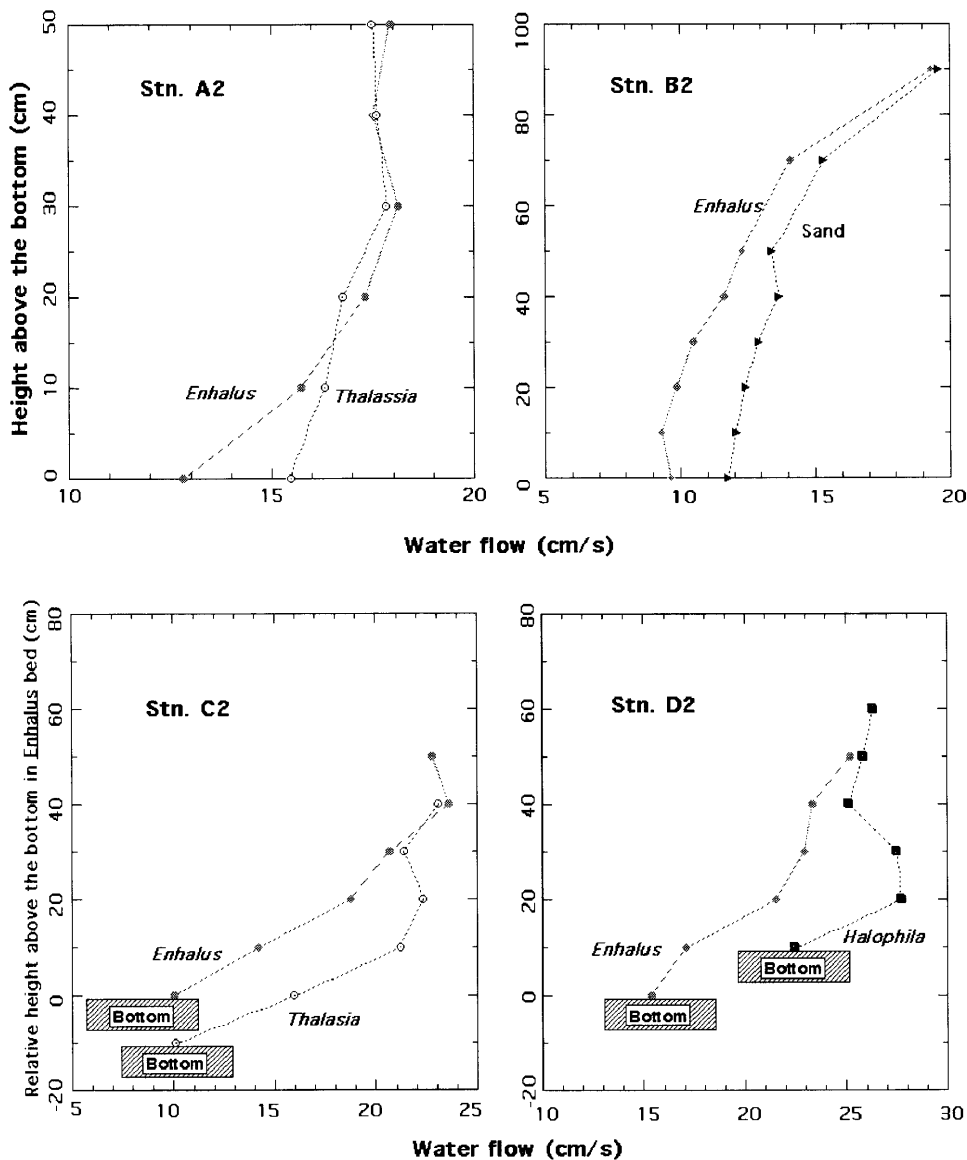


Fig. 3. Vertical profiles of water flow (cm/s) measured using gypsum balls for the different seagrass species and a sand bed at Stas. A2, B2, C2, and D2. The depths of the gypsum balls in the *Thalassia* bed at Sta. C2 and *Halophila* bed at Sta. D2 are corrected for the relative heights from the bottom of the *Enhalus* bed at each station.

reached about 70 cm above the bottom in areas with no large patches of the other seagrasses. The *Enhalus* blades were 30–40 cm long at Stas. A2, C2, and D2. Those of *Thalassia* were 5–10 cm and 10–15 cm at Stas. A2 and B2, respectively. Those of *Halophila* were 3–5 cm at Sta. D2. Often, the *Enhalus* shoots formed a ring around a center devoid of seagrass (Fig. 2), which sometimes contained one or several individuals of the infaunal bivalve *Pinna bicolor*.

The weather was good during the experiments. The sea was calm and the surface wave amplitude was very small. Tidal currents predominated.

Results

The vertical profiles of water flow above the bottom can be characterized as follows: (1) water flow at lower depths near the bottom was smaller than higher in the depth profile; (2) flow inside the *Enhalus* bed was much smaller than inside the other seagrass beds or the sand bed; (3) flow on the bottom inside the *Enhalus* bed was also smaller than elsewhere; (4) the slope of the intensity of water motion at the bottom of the seagrass beds was steeper than over the beds. At the same depth, the water flow at the bottom of the *Enhalus* beds was much smaller than that at the bottom of the *Thalassia* bed at Sta. C2 and at the bottom of the *Halophila* bed at Sta. D2 (Fig. 3). The greatest reduction in the rate of water flow was at the bottom of and over the *Enhalus* seagrass beds.

The sedimentation rates inside the *Enhalus* beds were about twice those of *Thalassia* beds at Stas. A2 and C2 (Fig. 4).

In the particle distributions of bottom sediments, the percentages of small particles increased from outside to inside the *Enhalus* patch at Sta. B2 (Fig. 5). The percentage of mud

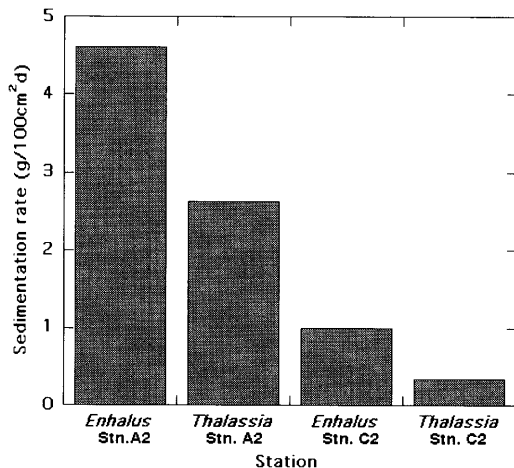


Fig. 4. Sedimentation rate inside seagrass beds and a sand bed at Stas. A2 and C2 from 2 to 4 December 1998.

in the sediments (particles < 0.25 mm) was also greatest in the center of the patch. At Sta. A2, the percentage of mud in the sediments in the *Enhalus* bed was greater than that in the *Thalassia* bed (Fig. 6).

The phi (F) units are expressed using the following equation:

$$F = -\log_2(\text{diameter of sediment in millimeters})$$

Therefore, a smaller F means a greater sediment diameter. The phi median diameter, Md_F , is F for the central 50% of the cumulative size-frequency distribution of the sediment. It is a measure of the central tendency of size distribution of sedi-

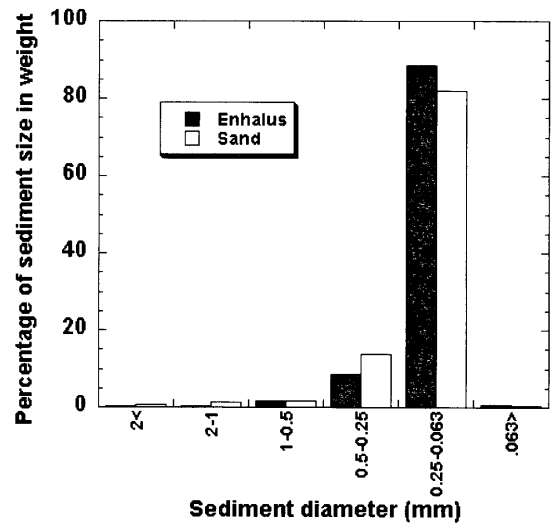


Fig. 5. Percentage of sediment diameter classes 0.063–0.25, 0.25–0.5, 0.5–1, 1–2, and >2 mm according to the total weight of the sediments in the *Enthalus* and sand beds at Sta. B2.

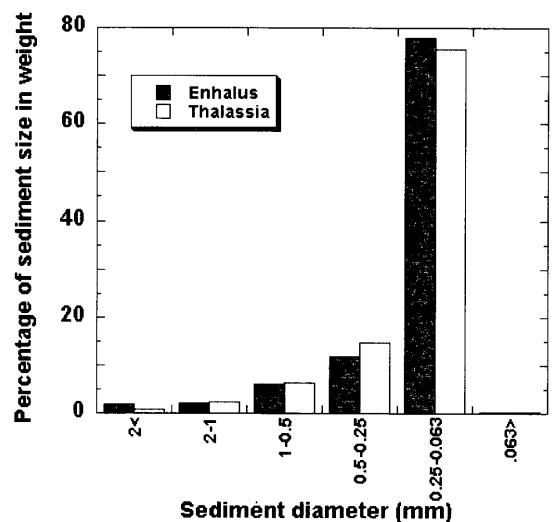


Fig. 6. Percentage of sediment diameter classes of 0.063–0.25, 0.25–0.5, 0.5–1, 1–2, and >2 mm according to the total weight of the sediments in the *Enthalus* and *Thalassia* beds at Sta. A2.

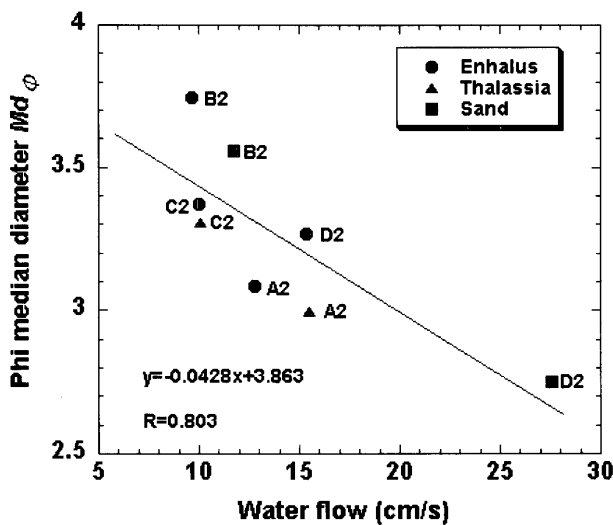


Fig. 7. Water flow and phi median diameter, Md_F , in *Enhalus* (closed circles), *Thalassia* (closed triangles), and sand (closed rectangles) beds at Stas. A2, B2, C2, and D2. The regression coefficient is 0.803.

ments (Inman 1963). It is preferred to the mean because it can be determined directly from the cumulative curve without interpolation and it is less influenced by an extreme skew than is the mean. The Md_F for the sediments at Stas. A2, B2, C2, and D2 was correlated with the water flow measured using the gypsum balls (Fig. 7). The sediments were classified as very fine sand (4 to 3 in F unit: 0.0625–0.125 mm), except for the sand bed at Sta. D2 (fine sand: 3 to 2 in F unit, namely, 0.125–0.250 mm). Md_F was greater in the *Enhalus* bed than in the *Thalassia* bed at Stas. A2 and C2. Md_F was greater in the *Enhalus* bed than in the sand bed at Stas. B2 and D2.

Discussion

There were clear differences in the vertical reduction of the water flow between the different seagrass species and the area with no seagrass and in the vertical profiles of water flow. This suggests that the bottom boundary layer is strongly influenced by the presence of seagrass. Sand-Jensen and Pedersen (1999) studied the vertical reduction of flow in submerged plant stands of different species in a stream and clarified that canopy height and density influenced the vertical flow profiles. Since tidal flow was the dominant flow at our study site, the same phenomenon occurs in seagrass beds.

The vertical profiles also showed that the vertical reduction in water flow caused by the seagrass bed depended on the blade length. The *Enhalus* blades (30–70 cm) were longer than those of the other seagrasses (*Halophila*: 3–5 cm; *Thalassia*: 5–15 cm) at the same stations. This is in accord with

the suggestion by Gambi et al. (1989) that water flow might decrease from the depth of the canopy of *Posidonia oceanica* L. to the depth of the rhizomes. The vertical velocity profile in seagrass canopies measured in unidirectional flow in laboratory flumes and in marine tidal waters showed a steep reduction in velocity immediately above the canopy, and relatively constant velocities with depth within the canopy (Gambi et al. 1990). Off Khao Bae Na, the tidal current predominated during the study period. Therefore, the laboratory experience is applicable to our results.

The retarded flow inside seagrass beds may influence the epifauna or benthos in the sediments. Scipione and Fresi (1984) studied the distribution of amphipods in a *Posidonia* bed and revealed a clear cenocline that was primarily under the control of environmental energy and hydrodynamic forces. A similar conclusion was drawn from investigations of the distributions of mollusks (Russo et al. 1984) and the epiphytic macroflora on *Posidonia* leaves (Cinelli et al. 1984). Toda et al. (1989) reported that more *Sargassum* propagules settled in artificial substrata where the wave motion was smaller than in near-shore waters. These facts suggest that the retarded-water-flow environment in a seagrass bed also benefits organisms living in the bed, including seagrasses themselves.

The flow patterns generated or modified by the presence of plants have strong implications for the metabolism, physical resistance, and development of the plants, as well as for sedimentation and the resuspension of sediment particles, and the growth and survival of microorganisms and invertebrates on plant surfaces or sediments shielded by the canopies (Gregg and Rose 1985; Tokeshi 1986; Sand-Jensen 1997). The sediment trap experiments showed that the sedimentation rate was higher inside the *Enhalus* beds than within the other seagrass beds with short blades. Divers observed only *Pinna bicolor*, a large shell, inside the *Enhalus* beds. The larger the *Enhalus* patch was, the longer the *Enhalus* blade length, and the greater the number of shells. Water flow was correlated with the median sediment diameter. At the same station, the median diameters in the *Enhalus* beds were smaller than those in the other substrata. These facts suggest that the shell depends on the supply of sediments trapped by the *Enhalus* blades for food, and that leaf density, length, and width influence the sedimentation rate by retarding the water flow. In stream plant stands, open canopies have high near-bed velocities (Sand-Jensen and Pedersen 1999), and little organic matter or fine mineral particles accumulate on the sediments (Sand-Jensen 1998). This is also true for our results for the vertical water flow profiles and sedimentation rates in patches of different seagrass species. The correlation between the median sediment diameter and water flow supports this specula-

tion.

In this way, seagrass beds create a unique physical environment in terms of water motion, as their buffering effect on water flow prevents erosion, owing to the weak water flow near the bottom. The physical environment created by a bed favors seagrasses ecologically (e.g., reduced erosion) and other marine organisms, including benthos in the sediments, epiphytes on the leaves, and larvae and juvenile marine animals.

Acknowledgment

We thank the staff of the Marine National Park Support Center, Thailand, for supporting our field research. We also thank Prof. I. Koike of the Ocean Research Institute, the University of Tokyo, and Prof. H. Mukai of Hokkaido University for their encouragement and Mr. C. Igarashi of the Ocean Research Institute for his help with analyzing particle size. This study was supported by a Grant-in Aid for the International Scientific Research Program (No. 09041147) from the Ministry of Education, Culture, Sports, Science and Technology, Japan.

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