NUTRITIONAL STATE AND ORGANIC MATTER DIAGENESIS IN AN ECOTONE OF HALOPHYTE AND PLANTED MANGROVE IN BAC LIEU PROVINCE, VIETNAM

Dissertation

For the Degree of

Doctor of Natural Science

Phạm Quỳnh Hương

Principal supervisor: **Professor Dr. Ulrich Saint-Paul**

(*Leibniz Center for Tropical Marine Ecology, Bremen*)

Co-supervisor: **Professor Dr. Gerhard Kattner**

(*Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research, Bremerhaven*)

ACKNOWLEDGEMENTS

I am grateful to my parents and my family for always giving me all the best and letting me grow up in their love. The faith they put in me is also the power for my steps forward.

I would like to express my heartfelt gratefulness to my principal supervisor, Professor Rubén José Lara, for his instruction and patience in reading as well as giving the comments on my thesis. I am very much grateful to my co-supervisor, Professor Ulrich Saint-Paul, for organizing the thesis defense.

I owe many thanks to Dr. Lê Xuân Thuyên for the valuable discussions, and Professor Viên Ngọc Nam for willingly providing the necessary information for my thesis, although he is very busy. I am very thankful to Dr. Trần Triết for offering me a good condition to work and study in my favorite field.

Profound appreciation is expressed to Dr. Karen Diele (Edinburgh Napier University) and Mr. Lê Hoàng Vũ (Department of Forest Management of Bạc Liêu province) for providing the useful data which importantly contributed to my study.

I would like to express my thankfulness to the ZMT staff, especially my Big mama Gaby Boehme, Matthias Birkircht, Dieter Peterke, Dorothee Dasbach, and Christina Staschok not only for their excellent techniques and kind help for my work, but also for the thoughtful care and attentiveness I received from them during my stays in Germany. I also thank Jennifer Rehren for her zealous help in grain size analysis and also for the interesting talks in the labs as well as during our walks. I am thankful to my dear friend Shilly Varghese for the warm weekends.

Very special and warm thanks are sent to Professor Hoàng Đức Huy and Dr. Nguyễn Thị Lan Thi for reading the different versions of my thesis and making it be improved. I also acknowledge my friends in the Department of Ecology and Evolutionary Biology for a nice working atmosphere and the field trips full of laughter.

Finally, I am greatly indebted to Dr. Julian Oxmann for his zealous help with my field trips in Gành Hào. I also thank Mr. Nguyễn Văn Hiền, Ms. Lê Ngọc Trân and my students in the University of Science for sharing the hard field work with me and making those days be unforgettable.

Erklärung:

Hiermit erkläre ich, dass ich die vorliegende Dissertationsschrift selbständig verfasst und keine anderen als die angegebenen Hilfsmittel verwendet habe.

Bremen, den 04.07.2014

Quynh Huong Pham

LIST OF CONTENTS

LIST OF ABBREVIATIONS

OC	organic carbon
C	carbon
TN	total nitrogen
N	nitrogen
OM	organic matter
P	phosphorus
AP	available phosphorus
IP	inorganic phosphorus
OP	organic phosphorus
NH_4^+	ammonium
NH_3	amonia
NO_2^-	nitrite
NO_3^-	nitrate
SO_4^{2-}	sulfate
PO_4^{3-}	phosphate
Cl	chloride
Na	sodium
K	potassium
Al	Aluminium
Fe	ferric
Ca	calcium
DOM	dissolved organic matter
POM	particulate organic matter
DON	dissolved organic nitrogen
Na_3PO_4	sodium phosphate
Na_2HPO_4	sodium hydrophosphate
KCl	potassium chloride
CH_3COONa	sodium acetate

Asp	aspartic acid
Glu	glutamic acid
Gly	glycine
Ala	alanine
Val	valine
Ser	serine
Thr	threonine
Leu	leucine
Ile	isoleucine
Lys	lysine
Arg	arginine
His	histidine
Orn	ornithine
Phe	phenylalanine
Tyr	tyrosine
β -Ala	beta-alanine
γ -Aba	gamma-aminobutyric acid
Tau	taurin
Met	methionine
Gluam	glucosamine
Galam	galactosamine
FITC-WGA	fluorescein isocyathionate-labelled wheat germ agglutinin
RFU	relative fluorescence unit
CFA	continuous flow analyzer
SRM	standard reference material
THAA	total hydrolyzed amino acid
N_{aa}	nitrogen in the otal hydrolyzed amino acid
C_{aa}	organic carbon in the otal hydrolyzed amino acid

LIST OF TABLES

LIST OF FIGURES

TÓM TẮT LUẬN ÁN

Rừng ngập mặn giữ nhiều vai trò quan trọng trong đời sống cũng như các hoạt động kinh tế - xã hội của con người. Tuy nhiên, diện tích rừng ngập mặn trên toàn thế giới đang suy giảm do nhiều nguyên nhân trong khi hiểu biết cụ thể về vai trò, chức năng của hệ sinh thái này vẫn chưa đầy đủ. Là quốc gia ven biển có diện tích rừng ngập mặn lớn, rừng ngập mặn ở Việt Nam là đối tượng của rất nhiều nghiên cứu khoa học. Tuy nhiên, những kiến thức về động thái dinh dưỡng và chất hữu cơ ở Việt Nam nói chung, và ở đồng bằng sông Cửu Long, hiện vẫn rất thiếu hụt. Nghiên cứu này được thực hiện để tìm hiểu động thái dinh dưỡng trong một hệ sinh thái rừng ngập mặn trồng lại trên ruộng muối bỏ hoang ở Gành Hào, tỉnh Bạc Liêu – một tỉnh ven biển miền nam Việt Nam – để tìm hiểu mối liên hệ giữa tình trạng dinh dưỡng với điều kiện môi trường nền trầm tích và động thái của chất hữu cơ trong nền.

Mẫu trầm tích và mẫu lá tươi của các loài thực vật được thu tại 8 kiểu sinh cảnh khác nhau dọc theo đường cắt dài khoảng 700 m trong mùa khô và mùa mưa năm 2009. Mẫu trầm tích được dùng để xác định hàm lượng chất dinh dưỡng (NH_4^+, NO_2^-, NO_3^- và P khả dụng cho thực vật) cùng với tổng lượng carbon hữu cơ (C_{org}) và nitrogen (N). Những số liệu này sẽ giúp đánh giá tình trạng dinh dưỡng trong khu vực nghiên cứu. Thành phần và hàm lượng các acid amin trong trầm tích được xác định để tìm hiểu quá trình phong hóa hữu cơ trong khu vực. Glucosamine, galactosamine cùng với thành phần và hàm lượng acid amin trong mẫu lá tươi được sử dụng để đánh giá nguồn gốc của vật liệu hữu cơ trong trầm tích. Phần đóng góp của chitin vào nguồn hữu cơ trầm tích cũng được định lượng theo 2 phương pháp. Việc xác định hàm lượng chitin trong trầm tích được thực hiện một cách trực tiếp qua sự tạo nối giữa 3 phân tử N-acetylglucosamine của chitin với wheat-germ-agglutinin được đánh dấu huỳnh quang (WGA-FITC). Bên cạnh đó, hàm lượng chitin còn được xác định thông qua hàm lượng glucosamine trong trầm tích.

Khu vực nghiên cứu bị thiếu hụt dưỡng chất nghiêm trọng, đặc biệt là N. Sự thiếu hụt N dẫn đến sự thiếu hụt P trong nền trầm tích. Hàm lượng N và P trong nền trầm tích

chịu sự chi phối của các đặc điểm lý hóa trong nền và sự có mặt hay vắng mặt thảm thực vật. Tỷ lệ C:N cho thấy vật liệu hữu cơ ở các tầng sâu trong khu vực nghiên cứu chủ yếu đến từ biển. Phần vật liệu hữu cơ có nguồn gốc từ thực vật trên cạn được tìm thấy chủ yếu ở tầng mặt, cho thấy rừng trồng và sự xâm lấn của Sam biển chỉ mới đóng góp vào nguồn hữu cơ trầm tích trong thời gian gần đây.

Hàm lượng hữu cơ trong trầm tích thấp hơn các rừng ngập mặn và các vùng ven biển khác, có lẽ là do tốc độ quay vòng hữu cơ trong nền trầm tích nhanh do nhiệt độ cao và các vết nứt sâu làm cho nền thoáng khí. Thành phần và hàm lượng acid amin trong trầm tích chịu ảnh hưởng của sinh khối cũng như thành phần và hàm lượng acid amin trong thực vật. Nhìn chung, hàm lượng acid amin giảm theo độ sâu trầm tích. Tuy nhiên, các hoạt động chuẩn bị đất khi trồng rừng đã gây xáo trộn xu hướng biến đổi theo tầng sâu của acid amin dưới tán rừng Cóc trồng.

Hàm lượng chitin xác định trực tiếp qua liên kết giữa N-acetylglucosamine với WGA vượt quá tổng lượng C_{org} trầm tích. Tuy nhiên, số liệu này vẫn cho thấy một liên hệ với số lượng mảnh vỏ khuê tảo tìm thấy trong nền. Hàm lượng chitin xác định thông qua glucosamine cho thấy chitin chiếm không đến 2% tổng lượng C_{org} và dưới 3% lượng N_{tot}. Trong các lớp trầm tích dưới sâu (30-35 cm), vỏ lột của cua là nguồn chitin chủ đạo trong khi ở các lớp trầm tích phía trên, chitin có nguồn gốc chủ yếu từ khuê tảo.

Tóm lại, những kết quả của nghiên cứu này cho thấy tình trạng dinh dưỡng cũng như động thái của chất hữu cơ trong nền trầm tích rừng ngập mặn trồng trong điều kiện khắc nghiệt như ruộng muối bỏ hoang chịu sự chi phối mạnh mẽ của thủy triều, thảm thực vật, bản chất nền trầm tích. Những ảnh hưởng này có thể liên quan đến hoạt tính của các vi khuẩn trầm tích giữ vai trò khoáng hóa và hòa tan N và P. Việc cải thiện điều kiện nền bằng những biện pháp lâm sinh và thủy lợi thích hợp sẽ tối ưu hóa hoạt tính của vi khuẩn, giúp nâng cao hiệu quả trồng rừng.

SUMMARY

Mangroves play many significant roles in human life and socio-economical activities. However, their coverage has seriously declined worldwide due to various reasons while understanding of the roles and functions of this ecosystem is still insufficient. With a vast area of mangroves along the coast line, several studies on this ecosystem have been done in Viet Nam. Notwithstanding, the knowledge of nutrient and organic matter dynamics in the mangroves of Viet Nam, in general, and in the Mekong Delta, in particular, is still a gap. This study was conducted to understand the nutrient dynamics in a mangrove replanted in an abandoned salt-pan in Ganh Hao, Bac Lieu province – a coastal area in the South of Viet Nam.

Sediments and fresh leaves were collected from 8 different landscapes along a transect which was *ca.* 700 m in length. Sampling was conducted in the dry and rainy season in 2009. The nutrient contents (NH_4^+, NO_2^-, NO_3^- and available P for plant uptake), total organic carbon and total nitrogen were determined to assess the nutritional state in the study area. The composition and concentration of the amino acids in the sediments were quantified to understand the organic matter diagenesis in the area. Glucosamine, galactosamine and amino acids in the fresh leaves were analyzed to find the source of the organic matter. The chitin content in the sediments was determined by 2 methods to calculate the contribution of chitin to the N pool. Chitin was directly quantified through the binding of N-acetylglucosamine and WGA-FITC. On the other hand, chitin was calculated from the concentration of glucosamine in the sediments.

The study area was subject to a serious deficiency of nutrients, especially nitrogen. The deficiency of nitrogen resulted in the deficiency of phosphorus in the sediments. The nitrogen and phosphorus contents in the sediments were controlled by the physico-chemical properties of the sediments and the vegetation. The carbon-to-nitrogen ratios showed that the organic matter in the deep sediments (30-35 cm) mostly derived from marine sources. The organic matter derived from terrestrial plants was found mostly in

the surface sediments. The forestation and the invasion of *Sesuvium portulacastrum*, therefore, have recently contributed to the pool of organic matter in the sediments.

The organic matter content in the study area was lower compared to other coastal areas, probably due to the higher turnover rate in the sediments, which resulted from the high temperature and the aeration in the sediment. The composition and contents of the sedimentary amino acids were affected by the composition and contents of the amino acids in leaves. In general, the contents of sedimentary amino acids decreased with depth. However, the soil preparation for mangrove plantation resulted in a disturbance in the variation trend with depth in the amino acid contents under the planted mangrove.

The chitin content directly quantified through the binding between N-acetylglucosamine and WGA-FITC exceeded the organic carbon content in the sediments. However, these chitin data revealed an ecological relationship between chitin and the diatom frustules. The content of chitin calculated from glucosamine concentration showed that chitin contributes less than 2% to the OC pool and less than 3% to the N pool. In the deep sediments (30-35 cm), the crustacean sheaths was the major source of chitin while in the shallow sediments, chitin mostly derived from diatoms.

In conclusion, this study showed that the nutritional state and the organic matter dynamics in a mangrove planed in extreme conditions was driven by tides, vegetation and the physico-chemical properties of the sediments. These effects might relate to the activities of sediment bacteria functioning in the nitrogen and phosphorus mineralization and solubilization. Improving the sediment conditions by irrigational solutions will help to maximize the bacterial activities and enhance the efficiency of mangrove plantation in abandoned salt-pans.

ZUSAMMENFASSUNG

Mangroven spielen eine bedeutende Rolle im Leben und den sozio-ökonomischen Aktivitäten der Menschen. Allerdings hat ihre Ausbreitung aus verschiedensten Gründen weltweit abgenommen, während das Verständnis über ihre Bedeutung und ihre Funktionen immer noch unzureichend ist. In einer großen Fläche von Mangroven entlang der Küste wurden in Vietnam zahlreiche Forschungen über dieses Ökosystem durchgeführt. Ungeachtet dessen gibt es in der Erkenntnis zur Dynamik von Nährstoff und organischem Material in den Mangroven Vietnams, im Allgemeinen, und im Mekong Delta, im Besonderen immer noch Lücken. Diese Studie wurde durchgeführt, um die Nährstoffdynamik in einer Mangrovenaufforstung in einem verlassenen Salinengebiet in Ganh Hao, Provinz BacLieu - einer Küstenregion im Süden Vietnams - zu verstehen.

Sedimente und frische Blätter wurden aus 8 verschiedenen Regionen entlang eines Transekts von ca. 700 m Länge gesammelt. Die Probenahme erfolgte in der Trocken und der Regenzeit im Jahr 2009. Die Nährstoffgehalte (NH_4^+, NO_2^-, NO_3^- und P verfügbar für Pflanzenaufnahme), der Gesamtgehalt organischen Kohlenstoffs und der Gesamtstickstoffgehalt wurden bestimmt, um den Nahrungszustand des Substrats im Untersuchungsgebiet zu erfassen. Die Zusammensetzung und die Konzentration der Aminosäuren im Sediment wurden quantifiziert, um die Diagenese des organischen Materials in diesem Gebiet zu verstehen. Glukosamin, Galaktosamin und Aminosäuren der frischen Blätter wurden analysiert, um die Herkunft des organischen Materials zu bestimmen. Der Chitingehalt in den Sedimenten wurde mittels zweier Methoden bestimmt, um den Beitrag des Chitins zum N-Pool zu berechnen. Chitin wurde direkt durch die Verbindung von N-Acetylglukosamin und WGA-FITC quantifiziert. Andererseits wurde Chitin aufgrund der Konzentration von Glukosamin im Sediment berechnet.

Das Untersuchungsgebiet unterlag einem ernsthaften Mangel an Nährstoffen, vor allem Stickstoff. Der Mangel an Stickstoff führte zu einem Mangel an Phosphor im

Sediment. Der Stickstoff und Phosphorgehalt in den Sedimenten wird von den physikalisch-chemischen Eigenschaften der Sedimente und der Vegetation beeinflusst. Das Kohlenstoff zu Stickstoff (C/N)-Verhältnis zeigte, das die organische Substanz in den tiefen Sedimenten (30-35 cm) hauptsächlich aus marinen Quellen stammt. Die organische Substanz aus terrestrischen Pflanzen wurde vor allem in den Oberflächensedimenten gefunden. Die Aufforstung und eine Invasion von *Sesuvium portulacastrum* haben in letzter Zeit zum Gesamtbestand der organischen Substanz in den Sedimenten beigetragen.

Der Gehalt an organischer Substanz in der Studie war niedriger im Vergleich zu anderen Küstengebieten wahrscheinlich aufgrund der höheren Umsatzrate in den Sedimenten des Untersuchungsgebietes, die auf die hohe Temperatur und die Belüftung im Sediment zurückzuführen sind. Die Zusammensetzung und die Konzentration der Aminosäuren im Sediment wurden durch die Zusammensetzung und die Inhalte der Aminosäuren im Laub beeinflusst. Generell wurde festgestellt, dass der Inhalt der Aminosäuren im Sediment mit der Tiefe abnimmt. Die Bodenvorbereitung für die Mangrovenanpflanzung führte jedoch zu einer Störung des Sediments. Dies wiederum führte zu einer Veränderung in der Schichtung der Aminosäuren unter der Mangrovenpflanzung. Der Chitingehalt übertraf den Gehalt an organischem Kohlenstoff im Sediment. Die Daten zum Chitingehalt weisen auf eine ökologische Beziehung zwischen Chitin und den Kieselalgentheken hin. Der Gehalt an Chitin, berechnet aus der Glukosamin-Konzentration zeigt, dass Chitin weniger als 2% zum OC-Pool und weniger als 3% zum N-Pool beiträgt. In den tiefen Sedimenten (30-35 cm) waren die Krebstier-Ausscheidungen die Hauptquelle von Chitin, während in den flachen Sedimenten Chitin hauptsächlich aus Kieselalgen stammt.

Zusammenfassend zeigte diese Studie, dass der Ernährungszustand und die Dynamik organischen Materials in einem Gebiet in dem Mangroven unter extremen Bedingungen angepflanzt wurden von den Gezeiten, der Vegetation und den physikalisch-chemischen Eigenschaften des Sediments geprägt sind. Der Einfluss dieser

Faktoren könnte in Beziehung zu Aktivitäten von Sedimentbakterien stehen, die in der Stickstoff und Phosphormineralisierung und Solubilisierung tätig sind.

Um die Produktivität von Mangrovenanpflanzungen in verlassenen Salinengebieten zu fördern, ist es sinnvoll Bewässerungssysteme einzurichten, um die Bakterientätigkeit zu erhöhen, die zur Verbesserung des Sediments führen.

1 INTRODUCTION

Mangroves are plant communities growing in the intertidal areas along the tropical and subtropical coasts (Clough 2013). They constitute a significant proportion of coastal flooded forests in these regions (Feller and Sitnik 1996). The term “mangrove” refers to an assemblage of 20 families with approximately 73 species (Spalding *et al*. 2010) including trees, shrubs and ground ferns (Clough 2013). The mangrove plants comprise 40-52 of true mangrove species (Feller and Sitnik 1996, Giesen *et al*. 2007) and many other species called “associate species” (Phan and Hoang 1993, Clough 2013). The true mangrove species are confined to the saline or brackish environments; the associate species are the inland plants which can be found behind the mangroves (Santisuk 1989). However, salts and tides are not obligatory for the mangrove plant species. All of those species can grow well in freshwater habitat but there they are out competed by the freshwater species (Kathiresan and Qasim 2005). The tidal flood and salinity are, therefore, the factors to eliminate other vascular plants which are not adapted to grow in the saline environments.

Mangroves distribute between the latitudes of 33^{o}N and 37^{o}S (Walsh 1974). Their growth, tree height, biomass and diversity decrease with the distance from the equator (Clough 1998). The range of mangrove occupation in terms of elevation is between the mean sea level and the mean high water. Consequently, mangroves are an indicator for the sea level changes.

There are many factors influencing the mangrove distribution. The mangrove plants require warm temperature for their growth. The temperature of sea water controlled the mangrove species composition (Blasco 1984). The best growth of mangrove was recorded in the brackish habitats (Kathiresan *et al*. 1996). Therefore, the high-biomass and well-developed mangroves colonized the coastal areas with high precipitation. The high input of rainfall maintains the mild salinity of the mangrove sediments through the salts dilution (Jimenez 1992).

Mangrove distribution is affected by tidal action, sedimentation and wave energy. It is found that mangroves hardly colonize the coasts with high wave energy and their growth is weak in stagnant waters (Kathiresan and Qasim 2005). Extensive mangroves occur on the vast deltaic plains formed by the accumulation of the fine sediments transported by large rivers (Feller and Sitnik 1996). The species distribution in the mangroves is controlled by the level and frequency of tidal inundation (Ong and Gong 2013). The inundation frequency, together with the temperature of sea water and the salinity of pore-water, determine the occupation of mangroves in the tropical coastal areas (Lara and Cohen 2006).

The best growth of mangrove plants is found in sediments formed by fine grains (*e.g.* clay) and mangroves help to increase organic content in sediments through litter fall (Bouillon *et al*. 2003). Leaf litter is the major contribution to the total litter production in mangroves (Sasekumar and Loi 1983, Siddiqui and Qasim 1990, Tam *et al*. 1998, Nga *et al*. 2005, Pham 2007). The atmospheric carbon sequestered in mangrove leaves can be transported to deep sediments by dwelling organisms (Camilleri 1992). Therefore, organic carbon (OC) is accumulated in the mangrove sediments. The organic matter (OM) can be also exported from mangroves through tidal action (Moran *et al*. 1991, Dittmar and Lara 2001). Consequently, mangrove ecosystems are at the same time a source and a sink for OC (Ong 1993).

Mangroves play a very important role in coastal fisheries as they supply vital nutrients to adjacent water bodies. Moreover, they are also a shelter for larvae and juveniles of marine organisms which are of high commercial values. Other values and benefits of mangrove ecosystems are summarized in Baba *et al*. (2013). In addition to the important socio-economical roles, mangroves are considered as a green rampart which can stabilize the shore lines and protect inland areas from natural calamities rising from the sea (Odum and Heald 1975, Pearce 1996, Mazda *et al.* 1997, Pearce 1999, Upadhyay *et al*. 2002, Dahdouh-Guebas 2006). An example for the safety of the hinterland

communities under mangrove's protection was recorded by Kathiresan and Qasim (2005).

In spite of many vital roles for human life, mangrove coverage seriously declined worldwide (Giri *et al*. 2011) due to various reasons (Alongi 2002, Giri *et al*. 2008). The loss of mangroves will be much more serious in the context of global climate change and related sea level rise (Gilman *et al*. 2008). The tidal inundation contributes significantly to mangrove plant growth and the stable development of this ecosystem through oxygen transportation to the roots (Clough and Attiwill 1975), supplying the ecosystem with nutrients (Pham 2007), sustaining the sediment salinity and spreading the propagules (Saenger *et al*. 1983). Nevertheless, the increase in the level and frequency of the tidal inundation may result in the decline of mangrove areas (Ong and Tan 2008). Once this green rampart collapses, the communities in the coastal areas will be threatened. Consequently, mangrove protection and rehabilitation in the coastal areas are exigent. Notwithstanding, there are various obstacles for this business. The failure of rehabilitation in tidal flats is mainly caused by the death of propagules once they are buried in the mud or eaten by macrofauna, or by restricted colonization due to the strong waves. The ratio of dead mangrove trees replanted in an eroded area was up to 50% (Conservation and Development of the Kien Giang Biosphere Reserve Project 2011). Therefore, site selection for mangrove restoration must be firstly considered.

Many sheltered areas along coasts are favorable sites for mangrove plantation. In Vietnam, those areas may include salt production sites in some coastal provinces, such as Thanh Hoa, Binh Dinh, Tra Vinh, Bac Lieu. The sea salt is mostly produced in accordance with traditional practices. In general, grounds for salt production must be compressed and smoothened before the sea water is conducted to the salt-pans. The water subsequently evaporates and the salt crystals are left in the surface sediments. The fine grains, *e.g.* clay, are predominant in the salt-pans structure in order to reduce the infiltration of saline water into deeper layers of sediments. The best infiltration coefficient for salt production is of 1-3 $mm.day^{-1}$ (Uong 1963). The compression and

smoothering of the ground carried out regularly during sea salt production result in strong reduction of the sediments. Thus, sulfate of ferric (Fe), manganese (Mn), and aluminum (Al) are removed from the sediments by sulfate reducing bacteria (McIntire *et al.* 1990, Machemer and Wildeman 1992). Therefore, sulfides accumulate in surface sediments and reduce salt quality. Consequently, salt-pans are left fallow after some years of production. These abandoned salt-pans may offer appropriate environments for mangrove restoration because they are less impacted by wave energy. Furthermore, the compressed sediments may cause the high levels of products from reducing processes which may be taken up by plants as nutrients (Bradley and Morris 1990). However, abandoned salt-pans are also a harsh environment for plant to survive. The sediments are very dry with extreme salinity. Thus, plant growth is restricted (Bernstein 1975, Sheldon 2004). The extreme salinity reduces the rate of gas exchange and light reactions in the photosynthesis (Biber 2006), impacts the nutrient absorption of plants (Brown *et al.* 2006), germination and growth of seedlings (Ye *et al.* 2005). High sediment salinity inhibits the nitrate (NO_3^-) and ammonium (NH_4^+) absorption of the mangrove plants (Odum 1988, Bradley and Morris 1991, Flores *et al.* 2000, Feller *et al.* 2003).

There were many trials on mangrove restoration in abandoned salt-pans in Can Gio (Vien Ngoc Nam pers. com.). Pham *et al.* (2007) planted the black mangrove (*Lumnitzera racemosa* Willd.) and yellow mangrove (*Ceriops tagal* (Perr.) C. b. Rob.) in an abandoned salt-pan previously colonized by Sea purslane (*Sesuvium portulacastrum* L.) and found that the survival rate was of 96 % and 34 % for *Lumnitzera* and *Ceriops*, respectively. *S. portulacastrum* is a prostrate succulent halophyte. They demand high light intensity for growth and can survive in the hypersaline coastal areas which are rarely inundated (Lonar and Judd 1997, Le *et al.* 2002). *S. portulacastrum* is able to accumulate the sodium (Na^+) ion in their leaves, stems and roots (Venkatesalu 1994). Under drought stress, concentrations of potassium (K^+), Na^+ and chloride (Cl^-) ion increase in plant tissues and hence, synthesis of proline is enhanced (Slama *et al.* 2006). The high concentration of proline in plant tissues helps to maintain the cell osmotic pressure for the

survival of *S. portulacastrum*, as well as other halophytes, in the hypersaline areas (Joshi 1980, Jenci and Natarajan 2003).

S. portulacastrum was proved to be able to enhance the sedimentary nutritional state through increasing the levels of OC, total nitrogen (TN) and phosphorus (P) in the abandoned salt-pans (Schmitt 2006, Tran 2007). However, the effects of this halophyte on the nutrient levels seem to be restricted in surface sediments and were attributed to atmospheric N fixation mediated by arbuscular mycorrhiza (Schmitt 2006). Intrusion of mycorrhiza into halophyte roots was recorded by many authors (Mason 1928, Khan 1974, Brundrett 1991, Beena *et al.* 2001). Tran (2007) found that the levels of TN and OC in the surface sediments occupied by *S. portulacastrum* were lower compared to the sites under young mangrove stands. The contribution of *S. portulacastrum* to the N pool of the sediments is probably not as important as the litter. Oxmann *et al.* (2010) recorded significant correlations between the concentrations of N and P in mangrove fresh leaves and the sediment pH within the root zone of 30-40 cm. This finding implies that the mangrove trees take up the required nutrients from the deep layers rather than the sediment surface.

The mangrove plant growth is influenced by sediment nutritional state. This state is controlled by environmental biotic and abiotic factors (Reef *et al.* 2010). Abandoned salt-pans are usually located at higher elevations in comparison with natural mangroves and the tidal inundation level and frequency at these salt-pans are lower than in mangroves. Therefore, they are more deficient in P compared to the areas at lower elevations (Lara *et al.* 2009). Many authors have recorded the deficiency of P as well as N in the coastal ecosystems (Boto and Wellington 1983, Feller 1995, Feller *et al.* 1999, Feller *et al.* 2002, Feller *et al.* 2003). The P deficiency results in the limited growth of the mangrove plants, their morphological and physico-ecological characteristics, and the primary production of the ecosystems (Feller 1996, Feller *et al.* 1999, Lovelock *et al.* 2004, Lovelock *et al.* 2006a, Lovelock *et al.* 2006b). However, Mendoza *et al.* (2011)

found that the concentration of available P for plant uptake (AP) in the sediments may control the species distribution in the mangrove ecosystems rather than their growth.

The AP concentration is influenced by tidal inundation (Silva and Sampaio 1998), tree density and biomass (Fabre *et al.* 1999). The sediment salinity and pH affects the AP concentration by controlling P sorption by OM (Koch *et al.* 2001). At the high concentration of chloride (Cl^-) and sulfate (SO_4^{2-}), phosphate (PO_4^{3-}) is competed by these anions for the sorption sites (Lara *et al.* 2009). The P sorption is promoted in the low-pH sediments because of the positive charge of the Al and Fe hydroxides under the acidic condition (Stumm and Morgan 1981). The sediment pH may also result in the shift in N, P limitation in the mangrove ecosystems (Oxmann 2007).

Although the low pH values support desorption of P from ferric oxyhydroxide and liberate AP (Mortimer 1971, Lindsay and Vlek 1977), they may cause unfavorable conditions for mangroves in terms of N nutrition. In anaerobic sediments such as compressed salt-pan, the pH is low due to the high level of hydrogen sulfide (H_2S) (Portela *et al.* 2011). Therefore, ammonia (NH_3) is produced and hence, nitrification is inhibited (Smith and Burns 1965, Joye and Hollibaugh 1995, Joye and Anderson 2008). Because of the low pH of the sediments, the balance $NH_3 + H_2O \Leftrightarrow NH_4^+ + OH^-$ shifts towards NH_4^+ accumulation (Fan and Mackenzie 1993), which results in poisonous effects on plants (Schenk and Wehrman 1979, Britto and Kronzucker 2002). The toxicity of NH_4^+ on the higher plants was reviewed by Britto and Kronzucker (2002).

Mangroves are known as one of the most productive ecosystems (Odum and Heald 1975) although they are subject to nutrient deficiency (Alongi and Sasekumar 1992). This paradox is explained by effective nutrient preservation (Reef *et al.* 2010) and nutrient recycling (Lee 1995) mediated mainly by sediment bacteria (Lathwell and Grove 1986, Vitousek and Sanford 1986, Lewis 1987, Ruess and McNaughton 1987, Alongi 1989, Hatcher *et al.* 1989, Singh *et al.* 1989, Furtado *et al.* 1990, Singh *et al.* 1991, Riviera-Monroy and Twilley 1996). The nutrient recycling is particularly requisite for the ecosystems which are usually subject to the nutrient deficiency (Sengupta and Chaudhuri

1991, Alongi *et al.* 1993, Vazquez *et al.* 2000). It is influenced by sediment conditions and more effective under aerobic condition (Hansen and Blackburn 1991, Alongi 1994, Dauwe *et al.* 2001). The number of sediment bacteria and their growth rates depend on the nutrient contents (Alongi 1994) and hence, correlate with the level of dissolved OM (DOM) and particulate OM (POM) in the environments (Meyer-Reil 1984, Moriarty 1986, Herndl *et al.* 1987). According to many authors, the sediment bacteria can absorb a great amount of NH_4^+ in marine and estuary environments (Wheeler and Kirchman 1986, Hoch *et al.* 1992, Middelburg and Nieuwenhuize 2000, Tungaraza *et al.* 2003). NH_4^+ is an important source of N for plants (Salsac *et al.* 1987) and acts as an intermediate in several metabolism processes (Joy 1988), but it can also inhibit the plant growth (Schenk and Wehrmann 1979). Hence, the NH_4^+ uptake by sediment bacteria may cause either a competition with plants for this N source or a reduction of ammonium toxicity on plants. The sediment bacteria can also take up dissolved organic nitrogen (DON) such as amino acids and urea in the oligotrophic ecosystems (Goldman and Dennett 1991, Kirchman 1994, Hoch and Kirchman 1995, Veuger *et al.* 2004). In addition to the important roles in recycling nutrients, the sediment bacteria act on the OM alteration through the preferential consumption of the organic compounds in the sediments (Wakeham *et al.* 1997, Benner 2003, Lee *et al.* 2004).

The diagenesis of OM in sediments is revealed through changes in composition and content of organic compounds resulted from their alteration. Organic compounds which can be subject to either loss or preservation, such as lignin and pigment (Cowie *et al.* 1992, Hedges and Prahl 1993, Boon and Duineveld 1996), can be used as indicators for the diagenesis. However, the distribution of these biomarkers can be limited in a certain group or found as traces only in the sediments (Dauwe and Middelburg 1998). Therefore, usage of these biomarkers may be limited in sediments receiving multiple sources of OM (Cowie and Hedges 1994).

Amino acids are biomarkers which have been used widely in recent studies on OM diagenesis (Lee 1988, Mingju *et al.* 1991, Cowie and Hedges 1994, Dauwe and

Middelburg 1998, Grutter *et al.* 2002, Unger *et al.* 2005, Davis *et al.* 2009, Zhang *et al.* 2012). These are biologically important organic molecules because they are the precursors of proteins which perform a vast array of functions within living organisms. Moreover, proteins account for a large proportion of POM (Cowie and Hedges 1994) and are an important source of N for the organisms, as N is a limiting factor in the coastal ecosystems (Tenore 1983, Le *et al.* 2012). Amino acids can be preferentially consumed or preserved during the diagenesis of OM in sediments (Knicker and Hatcher 1997). Consequently, changes in composition of the amino acids through depth profile can provide information of sediment history and help to predict reactivity of sedimentary OM (Davis *et al.* 2009).

The input of OM in mangroves or coastal hypersaline areas is very abundant, including autochthonous and allochthonous sources. In addition to leaf litter, dead animals, microbial necromass, planktons and marine bacteria also contribute to the sedimentary OM. Of the precursors of sedimentary OM, chitin is the second most abundant biopolymer, after cellulose only. This is a source of C and N (Montgomery *et al.* 1990) and its degradation plays significant roles in the C and N cycling (Gooday 1990). Nevertheless, the dynamics of chitin in the biosphere, in general and in the sediments of certain ecosystems, in particular, is still to a large extent unknown.

OBJECTIVES

There have been several studies on mangrove ecosystems in Vietnam, mostly focused on the biodiversity in mangroves (Phan and Nguyen 1999), mangrove structure and composition (Pham *et al.* 2012), and recently, the carbon sequestration of different plant species in mangroves (Vien *et al.* 2011, Nguyen 2012, Le 2013). Yet, studies on nutrient and organic matter dynamics in Vietnam mangroves are limited. Most of the available studies in this field were conducted in Can Gio Mangrove Biosphere Reserve, Ho Chi Minh City, *e.g.* the behavior of nutrients in a tidal creek (Pham 2007), P dynamics (Oxmann 2008), P exchange between mangrove and its adjacent river (Ho

2009), OM decomposition (Le 2011). The understanding of nutrient and OM dynamics in the vast mangrove area in the Lower Mekong Delta is still a gap.

In this context, the present study deals with the nutrient dynamics in an ecotone of a hypersaline surface and planted mangrove in the southern coastal sector of the Lower Mekong Delta. This is an abandoned saltpan, partly intruded by Sea purslane (*Sesuvium portulacastrum* L.) and partly covered by planted black mangrove (*Lumnitzera racemosa* Willd.). The ecotone, therefore, is exposed to the influence of various OM sources and expresses difference in physico-chemical conditions caused by the variation of elevations and the effects of vegetations. Thus, the tested hypotheses of the present study are:

1. Variation in topographic elevation, sediment physico-chemical properties and vegetation lead to the variation in sediment nutritional state along the ecotone. In this study, the coupling between the sediment physico-chemical conditions and its nutritional state is determined.
2. Contribution of different sources to the OM pool and their efficiency of mineralization are revealed in C:N ratios. Chitin is significant precursor of the sedimentary OM in the coastal area. The sedimentary chitin and C:N ratio along the ecotone were quantified to determine probable sources of chitin and their contributions to the N pool.
3. The history of sedimentary OM and their reactivity can be read and predicted through the characterization of the OM diagenetic status. The depth profiles of amino acids composition and concentrations, along with their contributions to the OC and N pool, allow assessing the diagenetic status of OM in the ecotone.

2 STUDY AREA

The sampling campaigns were conducted in a mangrove replanted in an abandoned salt-pan in Ganh Hao, Dong Hai district, Bac Lieu province, Vietnam. The territory of Bac Lieu province spreads from 9°00'00" N, 105°14'15" E to 9°38'9" N, 105°51'54" E. Bac Lieu is a coastal province locating in Ca Mau Peninsula, the South of Vietnam. The terrain is relatively even and flat but there are some sandy hills and stagnant hollows. The mean elevation is of 1.2 m above the mean sea level. There is an interlacing network of waterways in Bac Lieu province with the large canals such as Quan Lo, Phung Hiep, Canh Den, Pho Sinh and Gia Rai.

The climate in Bac Lieu province is driven by the tropical monsoon regime. The rainy season lasts from May to November and the dry season lasts from December to April. The annual precipitation is 2000-2300 mm. $year^{-1}$. The annual mean temperature is 26°C. The yearly temperature fluctuation is moderate. The highest and lowest temperature is 31.5°C and 22.5°C, respectively. The sunny periods varies between 2500 and 2600 hours. $year^{-1}$. The average relative humidity in the dry and rainy season is 80% and 85%, respectively. Bac Lieu province is located in a region which is rarely affected by typhoons and tropical low pressure. The influence of the flood regime of the Mekong River on Bac Lieu province is negligible. However, this region is strongly affected by a semi-diurnal tidal regime from the East Sea and the monsoon.

Acidic and saline soils predominate in Bac Lieu province. It accounts for *ca.* 93% of the total territory. Most of the soils in Bac Lieu are steady as they result from the deposition of alluvium over a long period. The forests account for *ca.* 2% of the provincial territory (5070 ha). Most of the forests are the replanted mangroves. The dominant planted genera are *Rhizophora*, *Avicennia*, *Lumnitzera* and *Ceriops*. In addition to the mangrove trees, *Casuarina equisetifolia* L. was also planted in the interior sandy sections and along the roads.

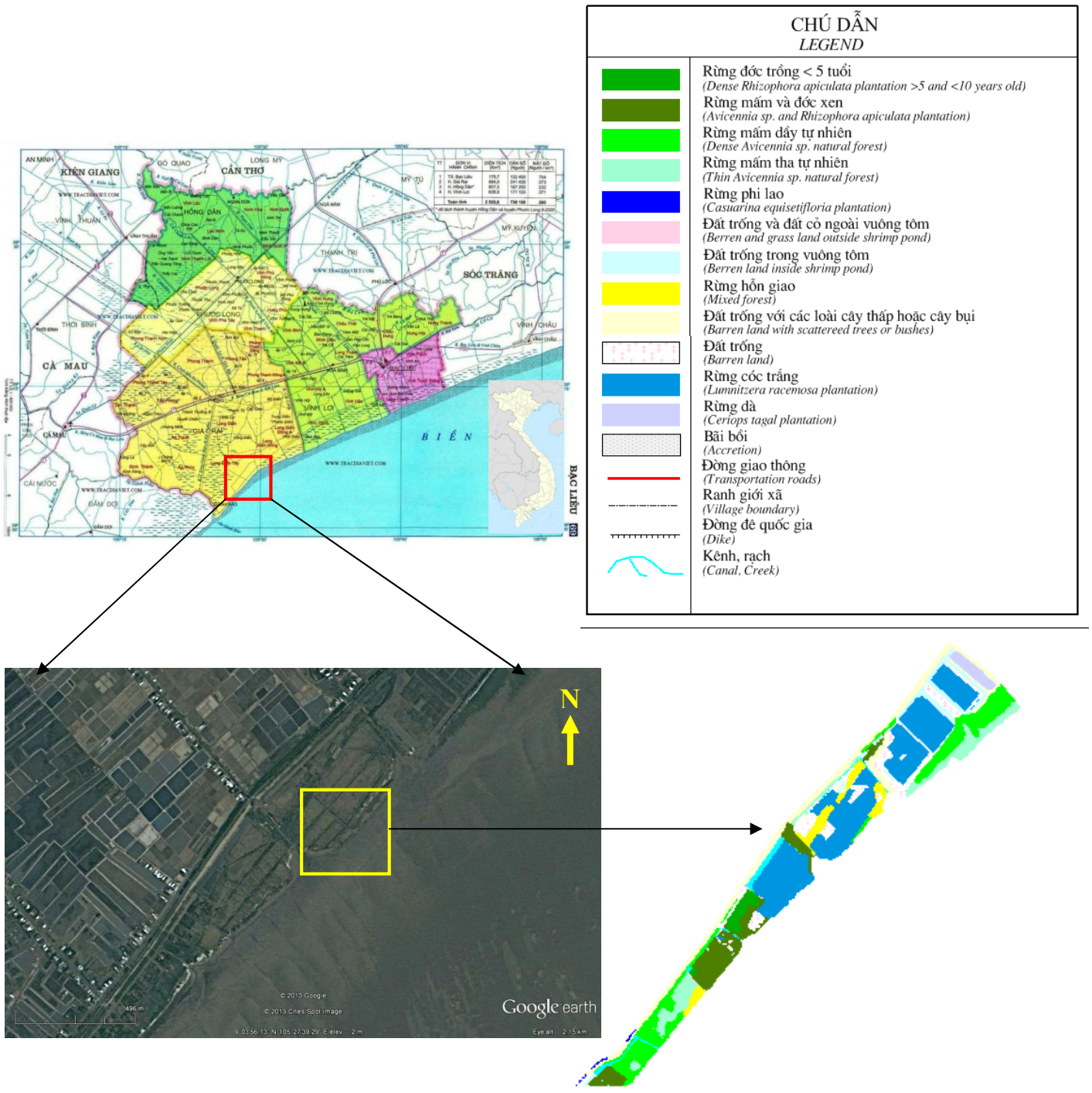


Figure 2.1: Position of the study area and vegetation distribution in Long Dien Tay Commune, Dong Hai District, Bac Lieu Province. The map of vegetation distribution was acquired from the Department of Forest Management in Bac Lieu province.

Due to the extended coastline (56 km) and the high species diversity and enormous productivity of adjacent fishing grounds, the economical development in Bac Lieu province focuses on seafood culturing, catching and processing. In the districts adjacent to the sea, including Dong Hai and Hoa Binh, salt production is also an important economic line. There are more than 2000 ha of salt-pans in Dong Hai district. The salt yield in Dong Hai district accounts for 80% of the whole provincial yield. The "Bac Lieu salt" is a well-known trade name because of its high quality and good taste. This salt does not have a tart flavor because the content of $MgCl_2$ is low and this area is not affected by Ca^{2+} in the sea water. The low concentration of OM in the salt-pan surface sediments, along with the negligible quantity of alluvium from the Mekong River, results in the low impurities in the salt. The high yield of salt results from the dominance of fine grains in the ground surface which reduces the downward infiltration of sea water.

Since 2009, the salt farmers in Bac Lieu province have applied a new method of salt production in which the salt-pan sediments are covered by canvas. The economical benefit from this method is higher compared to the traditional practices (Sach pers. comm.). Furthermore, the application of canvas may prevent the sediments from salinization. Nevertheless, a vast area of salt-pans used for salt production in accordance with the traditional protocol was abandoned due to the accumulation of the sulfate salts of heavy metals in the surface sediments. The wide area of abandoned salt-pans offers an ideal place for mangrove replantation. *Lumnitzera racemosa* (black mangrove) Willd. is often chosen because this species prefers low humidity, well-drained sandy mixed clay and grows well at higher elevations than other mangrove plants (FAO 2006).

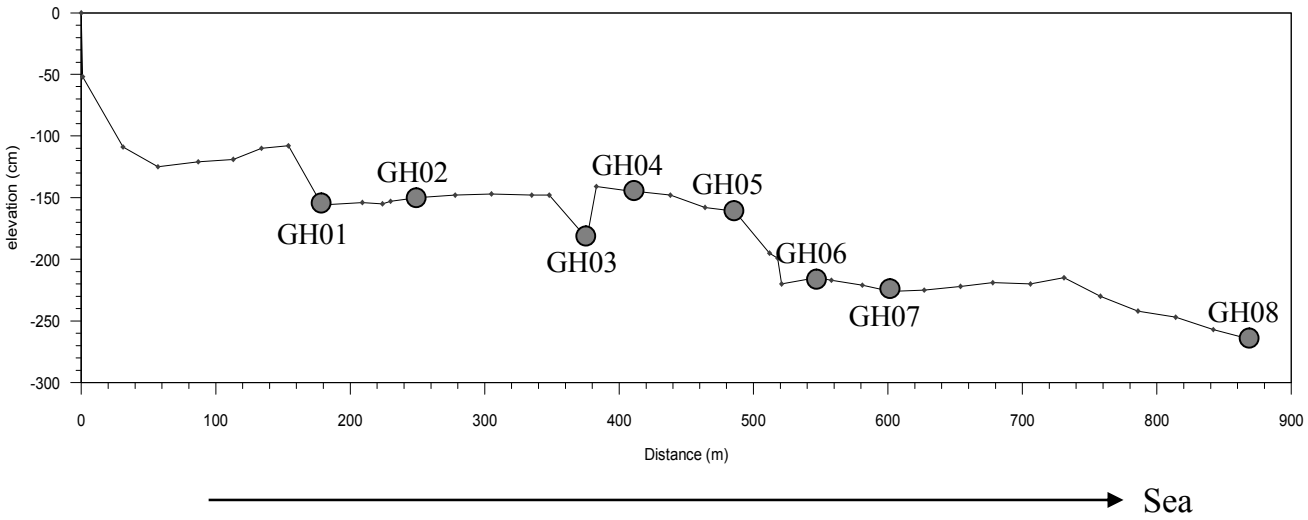
The samples of this study were collected from a black mangrove replanted in an abandoned salt-pan in Long Dien Tay commune, Dong Hai district. This mangrove was replanted in 1998 and is expected to function as a protective forest. In accordance with the data acquired from the Department of Forest Management in Bac Lieu province, the area of the replanted protective forest in Long Dien Tay commune is *ca.* 33 ha. The density is 10000 seedlings.ha^{-1}. Due to this low density, *Lumnitzera racemosa* ramify

rather than grow in height (Cao Huy Binh pers. comm.). The height of *Lumnitzera racemosa* trees measured in 2010 was of *ca.* 1 m. However, the stunt of *Lumnizera* trees may also result from the harsh conditions of the sediments, including high salinity and low humidity. Although *L. racemosa* is generally believed to be a drought and salt tolerant mangrove species, their growth is suppressed at salinity of 30-32 ‰ (Dissanayake and Amarasena 2009, Estomata and Abit 2011). In the dry season, the surface sediment in the salt-pans was partitioned by many deep rifts due to the sparse vegetation. In the interior sections, the replanted *Lumnitzera* growth was better and the trees are higher (Le Hoang Vu pers. comm.).

In the sampling area, there is a section of *ca.* 1 ha covered by *Sesuvium portulacastrum* and the mix stand of *Avicennia lanata* and *Sesuvium portulacastrum* (figure 2.2). The tree height of *A. lanata* measured in 2010 was *ca.* 2 m. The inundation frequency in this section is very low. It is flooded only during the very high tides.

Dong Hai district is strongly affected by a semi-diurnal tidal regime and the monsoon. Therefore, the shoreline is alternatively subject to the erosion and aggradation (Le *et al.* 2012). The drastic erosion occurs in the end of the year (October, November and December). The annual erosion rate from Ganh Hao to Rach Goc is of 20-30 $m.year^{-1}$ horizontally and *ca.* 1 $m.year^{-1}$ vertically (Hoang 2003). There is a natural regeneration of *A. lanata* in the tidal flat resulting in a fringe of this species which mean height is of *ca.* 3m along the shoreline.

Based on the difference in vegetation and visible characteristics of the sediments, a transect of *ca.* 700 m was set through eight different landscapes to catch the changes in nutrient dynamics and driving forces with the variable sediment conditions. The order of sampling sites is displayed in the figure 2.2. The codes and descriptions of the sampling sites are presented in the table 2.1.



GH_01 GH_02 GH_03 GH_04

GH_05 GH_06 GH_07 GH_08

Figure 2.2: The ecotones and elevations of the sampling sites. The topographic landmark, of which elevation was considered as 0 m, was the road along the study area.

Table 2.1: Codes and description of the sampling sites

Site code	Description
GH01	the mat of *Sesuvium portulacastrum*
GH02	the mix-stand of *Avicennia lanata* and *Sesuvium portulacastrum*
GH03	the man-made shallow creek parallel to the shoreline
GH04	the dwarf planted forest of *Lumnizera racemosa* (dwarf black mangrove)
GH05	the line of black mangrove with shell accumulation and exposed roots
GH06	the fringe of *Avicennia lanata* at the inner mud flat
GH07	the outer mud flat where *Avicennia lanata* was regeneting
GH08	the sand flat

3 METHODS

3.1 Sampling campaigns

The samples for this study were collected in May and October 2009, corresponding with dry and rainy season, respectively.

3.2 Sediments collection and preparation

In order to determine the sedimentary nutrient concentrations, elemental composition, composition patterns of amino acid and chitin amount, sediment samples were selected to cover all of the landscapes in the study area. Forty-centimeter sediment cores were taken by the piston corers. Physico-chemical properties, including temperature, pH and redox potential (Eh), were measured immediately by inserting electrodes into the sediment core through inlets on the wall of the corer. The sediment pH and Eh were measured with a sulfide resistant electrode ® SEA/SE (Schott, Germany). After the measurements, the sediment cores were sectioned into five-centimeter subsamples by a sterile knife. The subsamples at the depth from 0 to15 cm and 30-35 cm were stored at 4^{o}C during transportation to the laboratory.

3.3 Plant materials collection and preparation

At each sampling site, leaves of the dominant species were collected to survey the contribution of above ground plant biomass to the pool of OM in the sediment. Plant materials were washed with distilled water prior to wrapping in papers and drying at 90^{o}C in oven (Shell Lab, USA). When the samples reached the constant weight, they were homogenized by a Retsch ZM 100 (Germany) grinder and stored at room temperature until analysis.

3.4 Determination of sediment physico-chemical properties

3.4.1 Humidity

Fresh sediments from different depth intervals (0-5 cm, 5-10 cm, 10-15 cm and 30-35 cm) were homogenized in the container by a spatula prior to spreading in a sterile petri plate. The plates containing sediments were dried at 60°C until their weights were constant. Humidity was calculated by the following formula:

$$H\ \% = \frac{m_1 - m_2}{m_1 - m_0} \times 100$$

with m_0 : weight of the petri plate (g)

m_1 : weight of petri plate and fresh sediment (g)

m_2 : weight of petri plate and dry sediment (g)

The dry sediment was subsequently homogenized by grinding and passing through a sieve which was 250 μm in the mesh size.

3.4.2 Salinity

Fresh sediment (5 g) was suspended in 25 mL of distilled water during 12 hours at room temperature. The conductivity and temperature of the suspension were measured (TetraCon 96, WTW, Germany) afterwards and sediment salinity was calculated according to Ensminger (1996):

$$S\ ‰ = \frac{Kg\ (Vp + Vs)}{Vp}$$

with K_g : salinity of the suspension (‰)

V_s : water volume for sediment suspension (25 mL)

V_p : the volume of water in fresh sample calculated out of humidity and fresh weight of the sediment

$$Vp = \frac{m\,.\,H}{100}$$

with m : fresh weight of the sediment ($m_1 - m_0$) (g) and H : humidity (%).

3.4.3 Grain sizes

The fresh sediments were suspended in 30 mL of distilled water with 5 $g.L^{-1}$ Na_3PO_4. Dispersion was additionally facilitated by putting the beaker in an ultrasonic bath for a few seconds and subsequent heating in a sand bath at *ca.* 60°C for 10 minutes.

Grain sizes distribution in the sediments was determined by a laser diffractometer Horiba LA-300 (Japan).

3.4.4 Extractable inorganic N

Ammonium (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-) were analyzed automatically by a continuous flow analyzer Skalar-SAN-C^{++} (Germany). Prior to the determination, extractable NH_4^+ and NO_3^- were extracted by 2M KCl according to Keeney and Nelson (1982) and shaken for 30 minutes at 175 rpm at room temperature. The suspension was subsequently filtered to remove the sediment particles. The supernatants were transferred to test tubes for the analysis with the CFA Skalar-SAN-C^{++}.

The tube order and reagent compounds of the analyses were adjusted for the analysis of saline water. The salt effects were mostly compensated by the matrix photometer and the linearity range was bigger in comparison with single beam photometers.

The extractable inorganic N was analyzed in accordance with the method of Hansen and Grasshoff (1983) and the 5 cm cuvettes were used for the analyses of 3 mL of each sample. A ten point calibration was conducted with the mix standards for all parameters and the 5th standard was used as a quality control after every ten samples.

(i) NO_2^- and NO_2^- + NO_3^- analyses

NO_3^- was reduced to NO_2^- in a column of copperized cadmium. The buffer solution for this measurement was Imidazol 17 $g.L^{-1}$ adjusted to pH 7.5 with 32% HCl. The standard solution for nitrate was Merck Nr. 1.19811.0500 1000 mg/L NO_3 and for nitrite was Merck Nr. 9866 Titrisol 1000 mg/L NO_2. The absorbance was measured at

the wavelength of 540 nm and NO_3^- concentration was calculated by the difference between the sum of $NO_2^- + NO_3^-$ and NO_2^-.

(ii) NH_4^+ analysis

Extractable NH_4^+ concentration was determined by a colorimetric method based upon a reaction between ammonia and Berthelot's reagent to form blue indophenols. Berthelot's reagent is an alkaline solution of phenol and hypochlorite. Method accuracy was monitored using commercial standard (Merck Nr. 1.9812.0500 1000 mg/L NH_4)

3.4.5 Available P for plant uptake (AP)

AP in the sediment was extracted with Morgan solution according to the protocol of Morgan (1941) as described in Oxmann *et al.* (2010). The solution contains 100 g CH_3COONa in *ca.* 950 mL distilled water. After adjusting the solution pH to 4.8 by glacial acetic acid, distilled water was added to the final volume of 1000 mL. An amount of 0.25 g dry and homogenized sediment was suspended in 2.5 mL of Morgan solution by shaking at 175 rpm for 30 minutes at room temperature and subsequently centrifuged at 3500 rpm for 5 minutes. The supernatant was diluted for 10 times with distilled water and PO_4^{3-} determination was performed according to Riley and Murphy (1962).

3.4.6 Inorganic phosphorus (IP) and organic phosphorus (OP)

The dry and homogenized sediments were weighed into 2 ampoules with the same amounts (0.25 g). One ampoule was combusted at 245^{o}C for one hour in order to convert the organic forms of PO_4^{3-} to inorganic forms, while the other was placed at the room temperature. The combusted ampoule was used for total phosphorus (TP) and the other was used for IP determination. For PO_4^{3-} extraction, both of the ampoules were treated with 32 % HCl, sealed tightly and sonified for 10 minutes before heated at 110^{o}C for one hour. The supernatant was centrifuged and diluted for 50 times and PO_4^{3-} was determined according to Riley and Murphy (1962). The OP content was calculated by the difference between TP and IP.

3.4.7 Elemental composition in the sediments

For the quantification of TN and total OC, 10 mg of dry and homogenized sediment was weighed into tin cup and wrapped. Silver cups were used for OC analysis, because the sediment had to be acidified by 1 N HCl. Standard Leco 1013 was utilized for a fifteen-point calibration and as a quality control after every five samples. C and N were quantified with an elemental analyzer Fisons NA 2100 (Germany).

Samples and standards were delivered into the top of a quartz combustion tube by a rotating multiplace sample dropper which contained granulated chromium (III) oxide combustion catalyst. All combustible materials in the sample were flash burned in a pulse of pure oxygen at $1200^{o}C$ and the combustion products including CO_2, NO_x and H_2O were swept out the bottom of the tube by a constant stream of non-reactive helium carrier gas. CO_2 and other nitrogen bearing combustion products such as N_2 and NO_x passed over the combustion tube to another furnace containing copper granules at $650^{0}C$ where all molecules of NO_x gave up their oxygen to the hot copper and emerged as pure N_2. Water from the sample was removed by a trap containing magnesium perchlorate. After passing through a gas chromatograph column, the clean gases were separated into N_2 and CO_2 and these ones reached the mass spectrometer at different times: N_2 was the first one eluted and CO_2 was the latter. These molecules were ionized by a beam of electron generated from the ion source and subsequently the ions were collimated in a focused beam and accelerated into the flight tube. The ion beams entered a strong magnetic field created by an electromagnet which performed the actual mass separation. Ions in the field were deflected into circular paths whose radii were proportional to their masses.

3.4.8 Amino acids and amino sugars

The weight of sediment for amino acids and amino sugars analyses were calculated based on their level of OC to determine the range of OM in the samples. The sediments were spiked with 4 mL of 6 N HCl in the ampoules. Oxygen was purged from the ampoule by a flow of nitrogen gas to avoid oxidation. After sealing the ampoules, amino acids and amino sugars were hydrolyzed at 110^{o}C for 22 hours. When the hydrolysis was accomplished, 1 mL of the hydrolysate was evaporated at 60^{o}C, 40 mbar. The residue was dissolved by the sodium citrate buffer, pH 2.65 and frozen until the determination of amino acids and amino sugars were performed with low pressure liquid chromatography (Analyzer: Biochrom 30, Fluoreszenzdetector: F-1080 by Merck Hitachi). The amino acids, Gluam and galactosamine were detected in the following order:

Abbreviation	Aminoacid	Formula	M [g/mol]
TAU	Taurine*	$C_2H_7NO_3S$	125.1
MET-Sulfon	Methionine sulfone*	$C_5H_{11}NO_4S$	181.2
ASP	Aspartic acid*	$C_4H_7NO_4$	133.103
THR	Threonine*	$C_4H_9NO_3$	119.119
SER	Serine*	$C_3H_7O_3N$	105.093
GLU	Glutamic acid*	$C_5H_9NO_4$	147.129
GLY	Glycine*	$C_2H_5NO_2$	75.067
ALA	Alanine*	$C_3H_7NO_2$	89.093
VAL	Valine*	$C_5H_{11}O_2N$	117.146
MET	Methionine*	$C_5H_{11}NO_2S$	149.212
ILE	Isoleucine*	$C_6H_{13}NO_2$	131.173
LEU	Leucine*	$C_6H_{13}NO_2$	131.173
TYR	Tyrosine*	$C_9H_{11}NO_2$	182.197
PHE	Phenylalanine*	$C_9H_{11}NO_2$	165.189
GLUAM	Gluam-hydrochloride	$C_6H_{13}NO_5$	215.64
GALAM	Galactosamine-hydrochloride	$C_6H_{13}NO_5$	215.64
b-ALA	ß-Alanine	$C_3H_7NO_2$	89.093
g-ABA	g-Amino-butyric acid*	$C_4H_9NO_2$	103.1

HIS	Histidine*	$C_6H_9N_3O_2$	155.155
ORN	Ornithine*	$C_5H_{12}N_2O_2$	168.6
LYS	Lysine*	$C_6H_{14}N_2O_2$	146.188
AMM	Ammoniumsulfate*	$(NH_4)_2SO_4$	132.1
ARG	Arginine*	$C_6H_{14}N_4O_2$	174.201

**Amino acids containing a concentration of 2.5mM (Lab-service Onken) GALAM, GLUAM and b-ALA in hydrolysate have been purchased from Sigma Aldrich and added manually.*

3.4.9 Chitin

Chitin in the sediment was quantified directly through the coupling between chitin and fluorescein isocyathionate-labelled (FITC) wheat germ agglutinin (WGA) according to Montgomery *et al.* (1990). This method was successfully applied for chitin quantification in the sediment traps. In addition, they demonstrated that the clay grains, cellulose and bacteria, which are abundant in our study area, did not interfere the fluorescence signals. The method of Montgomery *et al*. (1990) based on the binding between wheat germ agglutinin (WGA) and sugar (Allen *et al*. 1973, Roth 1978), and the utilization of flurorescein isothiocyanate-labeled (FITC) as fluorescent probes (Kruszewski *et al*. 2008). The fluorescence of FITC-labeled WGA molecules binding with chitin is eliminated. Therefore, the fluorescence intensity is inversely correlated with chitin concentration.

FITC-WGA solution was prepared by mixing 200 µL stock FITC-WGA (Biozol, Germany) with 50 mL phosphate buffer (Na_2HPO_4 0.1 M, pH 9.2). The decrease in fluorescent signal which referred to the chitin concentration was measured against a six-point calibration curve. Chitin stock standard solution was prepared by manually suspending 1.8 mg chitin from crab shell (Sigma-Aldrich, USA) in 15 mL phosphate buffer. Concentrations of six calibration points are present in the table 3.1. The stock standard solution was shaken well before every pipetting to make sure that the chitin flakes distributed evenly in the buffer. As the chitin flakes do not dissolve in phosphate buffer, the transfer of chitin from the stock to the working standard solutions might not be exact. This error was reduced by the duplicate calibrations.

Table 3.1: Concentrations of chitin calibration points

Calibration point	Chitin stock standard (mL)	Phosphate buffer (mL)	Chitin concentration (µg/5mL)	Chitin concentration (µg/mL)
1	0.000	5.000	0	0
2	0.500	4.500	60	12
3	1.000	4.000	120	24
4	1.500	3.500	180	36
5	2.000	3.000	240	48
6	2.500	2.500	300	60

Firstly, 30 mg of the dry and homogenized sediments were incubated in 5 mL phosphate buffer and 2 mL FITC-WGA solution by shaking at 1000 rpm at 30^{o}C for 16 hours. The sediment grains were subsequently removed by filtering through GF/F (0.7 µm pore size) and the aqueous phase were used for fluorescence signal measurements. The amounts of sediments were then reduced to 10 mg to minimize the impacts of humic substance on the fluorescence intensity while the volume of buffer and FITC were kept intact. An amount of 10 mg of each sample was duplicated weighed. One subsample was used to measure the fluorescent intensity of the sediment itself (RFU_s) and the other was used to determine the total fluorescent signal of chitin concentration in the sediment and the sediment itself (RFU_t). The chitin concentration is the difference between these two fluorescent units ($RFU_c = RFU_t - RFU_s$). Kinetics of the blank and calibration points were carried out to find out the large and stable calibration range with the highest slope. The samples for kinetics experiment were incubated in 8 mL vials with 5 mL phosphate buffer and 2 mL FITC-WGA and shaken at 2062 rpm at room temperature.

3.5 Elemental composition, amino acids and amino sugars in plant materials

3.5.1 Elemental composition

A quantity of 1000 μg of Standard Reference Material (SRM) 1515 and powdered samples were weighed into the tin cups. The standard was used for a fifteen point calibration and as a quality control after every five samples. Because of the very low content of inorganic C in plant materials, the samples were not acidified with 1N HCl acid. Consequently, total C was considered as total OC in the samples.

C and N content in the plant materials were quantified with the elemental analyzer Fisons NA 2100 (for details see 3.4.7).

3.5.2 Amino acids and amino sugars

The powdered plant materials were treated in the similar protocol with the sediments for the determination of amino acids and amino sugars. For details see 3.4.8.

3.6 Data analysis

The data analysis was carried out with Statgraphic Centurion XV. The comparison of means was conducted by running a t-test with $\alpha = 0.05$. The effects of site and depths on the sediment properties, as well as the interaction between those factors are tested by multifactor-ANOVA analysis. Correlations between the properties are tested by the Pearson product-moment correlation. The correlations are accepted when p-values are less than 0.05.

4 RESULTS

4.1 Grain size distribution

The grain size distribution in Ganh Hao sediments is presented in figure 4.1. The study area was dominated by the medium silt with a proportion of 32.2 %. Sand and clay accounted for 3.1 and 12.5 %, respectively. The grain size distribution was comparatively similar through the sediment depths at the interior sites. However, at GH02, the fine sand decreased more than 90% from 0-5 cm to 5-10 cm. The proportion of sand at the more tidal-affected sites were higher compared to the interior sites. The medium sand accounted for 53 % in the surface sediment at GH08 and 23 % in 5-10 cm at GH05.

The clay, fine and medium silt content significantly decreased from the dry and saline sites towards the tidal-affected sites ($p < 0.001$). Within 0-15 cm, clay, fine and medium silt decreased more than 95 % from GH04 to GH08 but the difference between their contents in GH01 and GH03 was less (lower than 37 %). In 30-35 cm, the clay, fine and medium silt decreased *ca.* 75 % from GH04 to GH08 and *ca.* 5 % from GH01 to GH03. On the contrary, the fine sand proportion significantly increased towards the sea ($p < 0.001$). The fine sand content at GH08 was 3 times higher than at GH05. No significant difference between depths was found at any class of grain size ($p > 0.05$). The large proportion of medium sand found at 5-10 cm depth at GH05 indicated the influence of tidal action in the past. The topography at GH05 was elevated as this is the saltpan wall. Hence, the coarse grains transported from the sea during erosion were accumulated here. The absence of medium sand in the surface sediment at this site can be a proof that in the recent times deposition was a more dominant process in the hydrological regime in Ganh Hao.

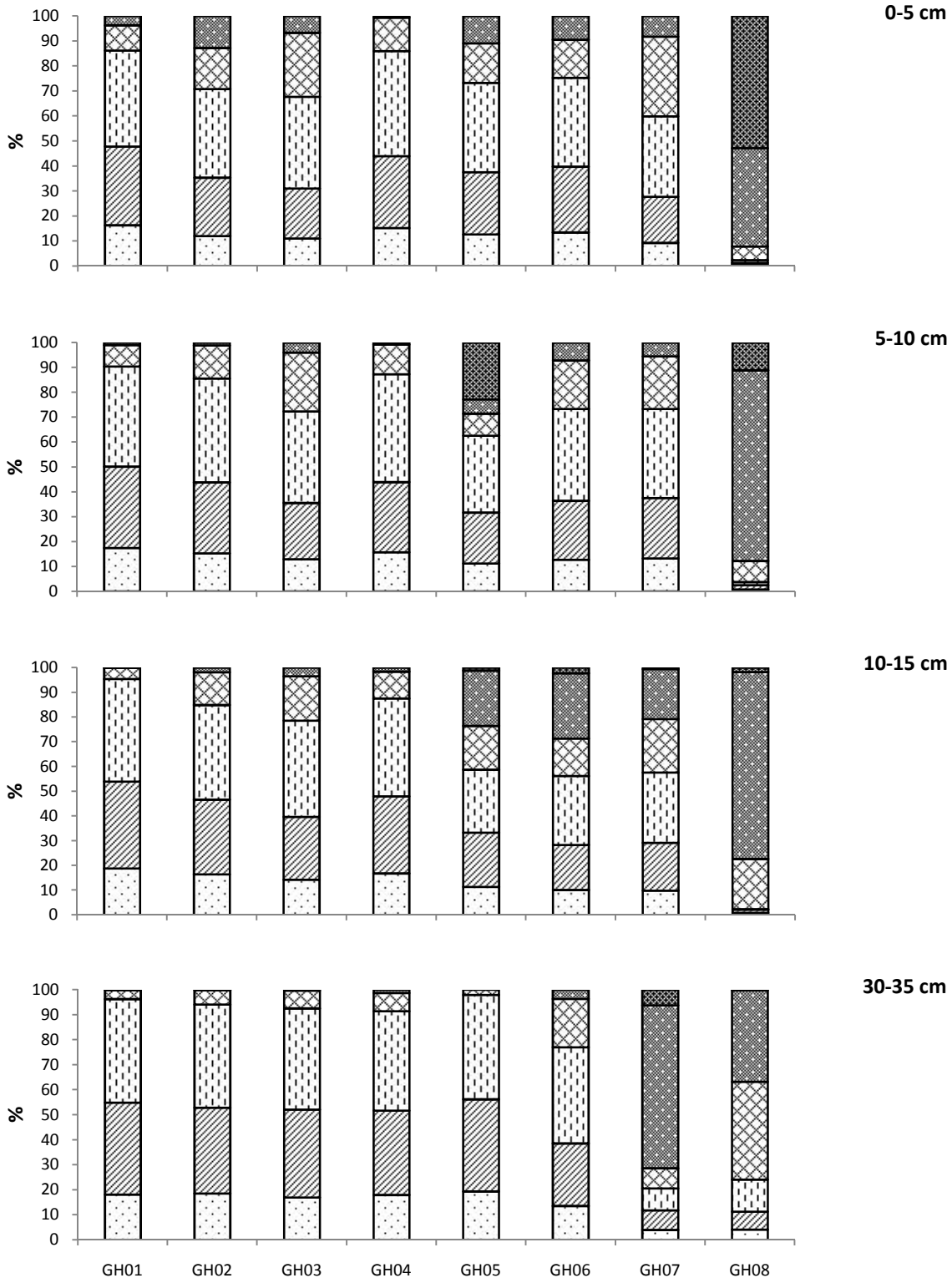


Figure 4.1: The grain size distribution in Ganh Hao sediments. clay, fine silt, medium silt, coarse silt, fine sand, medium sand.

4.2 Physico-chemical properties

The basic physico-chemical properties of the sediments are presented in table 4.1 as the averages of the whole study area (8 sampling sites) at each depth. Sediment humidity varied from 17.7 % to 42.2 % and from 21.1 % to 40.4 % in the dry and rainy season, respectively. Within the 0-15 cm sediment interval, humidity increased from GH01 to GH03 and from GH04 towards the sea (figure 4.2). The highest values of humidity were found at GH07 in both of the sampling seasons in the upper layers (figure 4.2). The tendency of variation was not evident in the depth of 30-35 cm and the high values of humidity (higher than 35 %) were found at the creek (figure 4.2). Neither depth trends nor seasonal effects were found for sediment humidity (table 4.2). Nevertheless, there were significant interactions between season, depth and location (table 4.2).

Table 4.1: The basic physico-chemical properties of the sediment in the dry and rainy season. The presented values are averages of 8 sampling sites.

Depth (cm)	pH		Humidity (%)		Salinity (‰)	
	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season
00-05	7.28 ± 0.37	7.36 ± 0.12	29.79 ± 3.77	31.19 ± 2.80	33.22 ± 11.82	18.94 ± 4.19
05-10	7.23 ± 0.29	7.28 ± 0.09	29.84 ± 3.35	29.77 ± 2.81	35.01 ± 8.13	26.68 ± 6.34
10-15	7.18 ± 0.28	7.18 ± 0.15	28.88 ± 3.17	29.34 ± 2.48	33.85 ± 6.72	27.02 ± 5.98
30-35	7.05 ± 0.26	7.07 ± 0.15	30.84 ± 2.36	30.04 ± 3.01	32.45 ± 4.65	30.18 ± 5.71

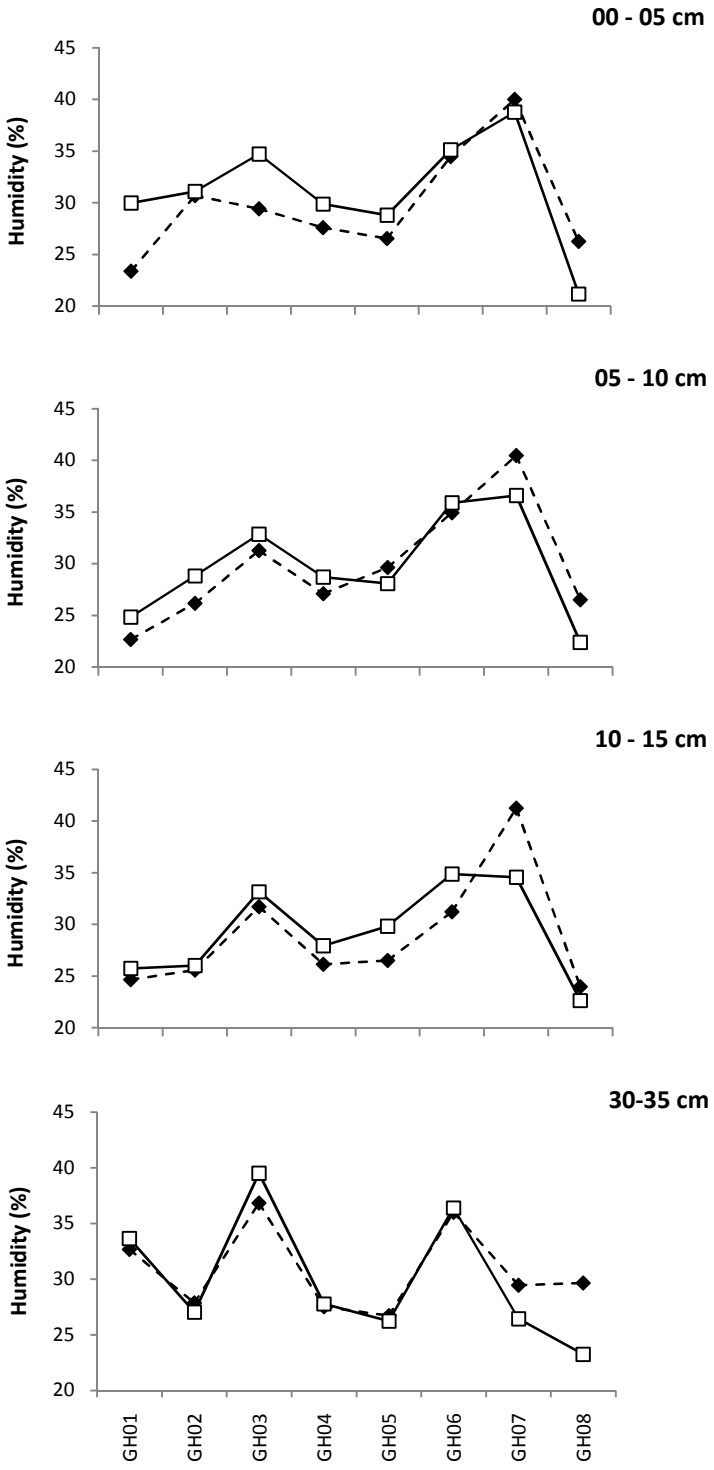


Figure 4.2: Variation and seasonal comparison of sediment humidity. ◆ dry season, □ rainy season

Sediment salinity decreased from GH01 to GH05 with a sudden increase in the dwarf black mangrove (GH04) before smoothly increasing towards the sea (figure 4.3). The salinity was significantly higher in the dry season (table 4.2). There were significant interactions between depth, season, and location (table 4.2). The salinity was extremely high at the site of dwarf *Lumnitzera racemosa* (GH04) and the Sea purslane mat (GH01), especially in the dry season, up to 76.46 ‰ and 89.55 ‰, respectively. The sediment salinity was lower in the depth of 30-35 cm and the fluctuation was more stable, but the highest values were even found in the sites where *S. portulacastrum* occurred (figure 4.3).

Table 4.2: The influence of sediment depth, seasons, and sampling sites on the sediment characteristics. (a) x (b), (b) x (c), (a) x (c) and (a) x (b) x (c) express the interactions between depth (a), season (b) and site (c). Season, sampling depth and site are the factors and coded for the multifactor-ANOVA analysis. Season (1): dry and (2): rainy. Depth (1): 0-5 cm, (2): 5-10 cm, (3): 10-15 cm and (4): 30-35 cm. Site (1): GH01, (2): GH02, (3): GH03, (4): GH04, (5): GH05, (6): GH06, (7): GH07 and (8): GH08.

	Humidity (%)	Salinity (‰)	pH	$N\text{-}NH_4^+$ (umol g^{1-})	$NO_2 + NO_3$ (ug g^{-1})	AP (umol g^{-1})	OC (umol g^{-1})	TN (umol g^{-1})	Ptot (umol g^{-1})	IP (umol g^{-1})	OP (umol g^{-1})
Depth (a)	ns	*	**	*	ns	ns	**	**	**	**	ns
Season (b)	ns	**	ns	**	**	ns	ns	ns	ns	ns	**
Site (c)	**	**	**	**	**	**	**	**	**	**	**
(a) x (b)	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns
(a) x (c)	**	*	ns	*	ns	ns	**	**	**	**	ns
(b) x (c)	*	**	**	**	*	*	**	**	ns	*	ns
(a)x(b)x(c)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

*****: p < 0.01; *: p < 0.05; ns: non-significant***

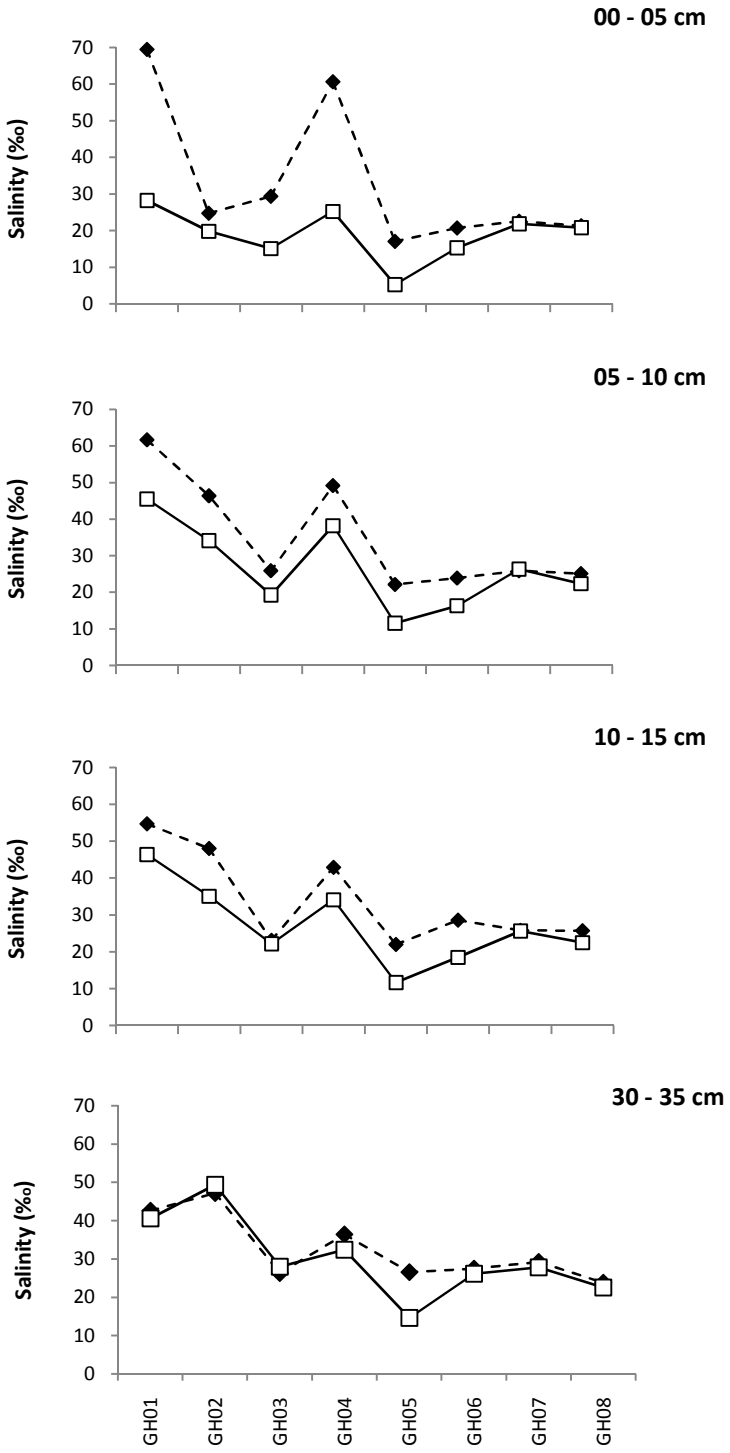


Figure 4.3: Variation and seasonal comparison of sediment salinity. ◆ dry season, □ rainy season.

The sediment pH decreased gradually with depth (table 4.1). The pH values tended to increase from GH01 to the carbonate site (GH05) and from the mangrove fringe (GH06) to the sand flat (figure 4.4). Spatial pH variations were more pronounced in the dry season. In all of the sampling depths, the pH was higher during the rainy season as compared to the dry season, but no statistically significant difference between the periods was recorded (table 4.2). In the dry season, pH varied between 5.92 and 8.63. The range was narrower in the rainy season with the variation between 6.37 and 7.91. The interior sites were influenced by the seasonal factors while the pH values of the flooded sites were stable during the sampling year (figure 4.4).

The Eh varied between -242 and 295 mV in the dry season. The sediments of GH01, GH02, GH04 and GH05 were very aerated in the dry season (figure 4.5). There were no remarkable changes in Eh in the upper layers from GH01 to GH05. The Eh may be influenced by the tidal inundation and the grain size composition in the sediments. The proportion of the grains whose diameters were smaller than 20 μm (clay to medium silt fractions) in the surface sediment at GH07 was *ca.* 60%, lower as compared to the other landward sites. Nevertheless, the Eh at this site was the only negative value in the surface sediments at all depths (figure 4.5) and probably resulted from the water logging, as this site is topographically lower than the others (figure 2.2). Clay and fine silt significantly correlated with the Eh (figure 4.6).

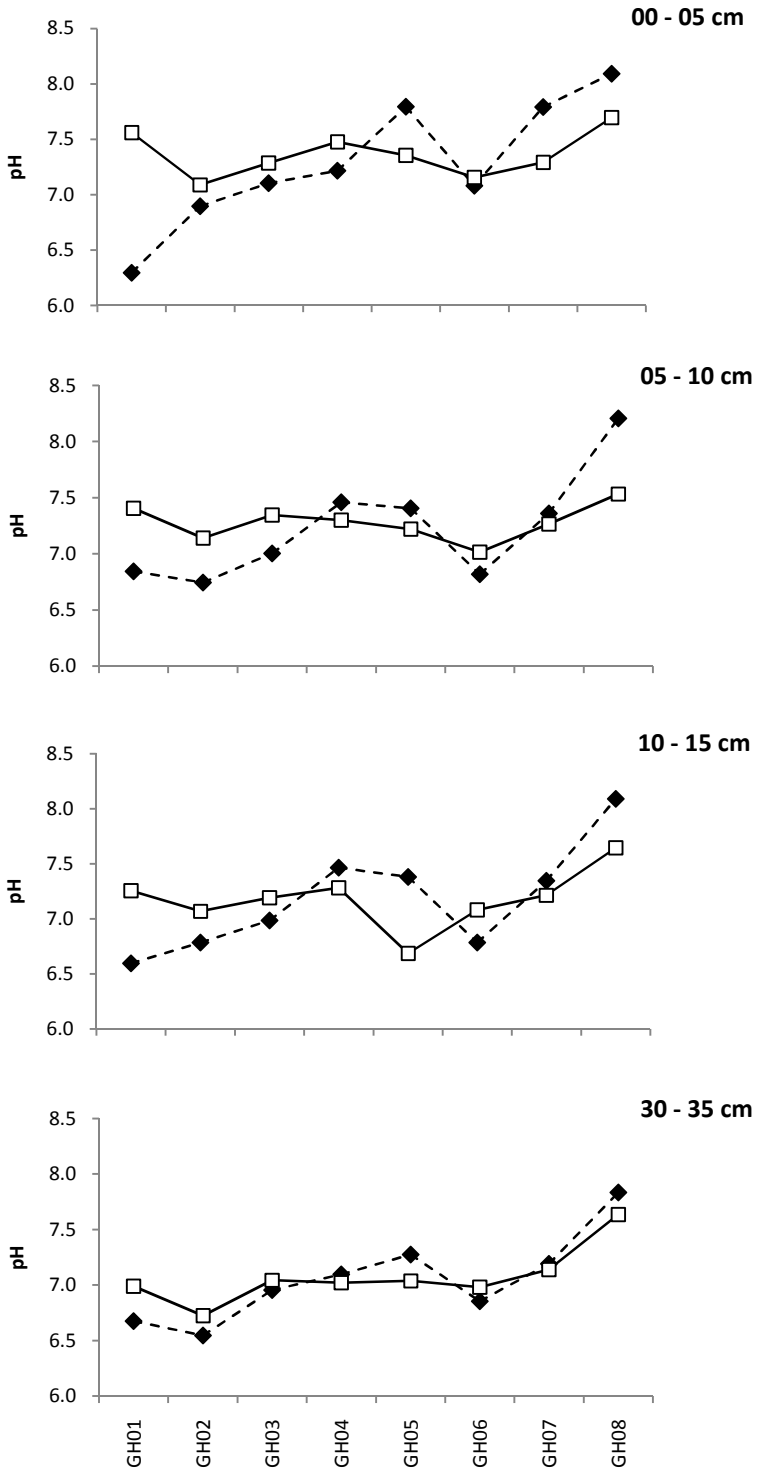


Figure 4.4: Variation and seasonal comparison of sediment pH. ◆ dry season, □ rainy season.

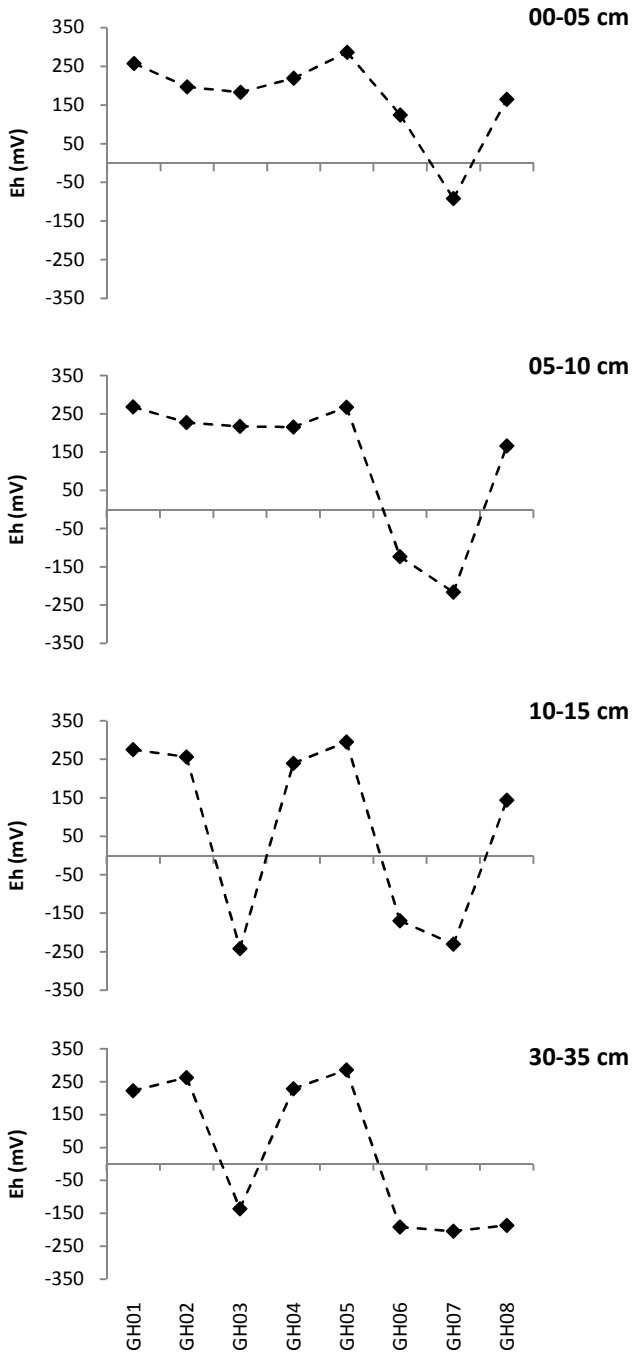


Figure 4.5: Variation of sediment Eh in the dry season.

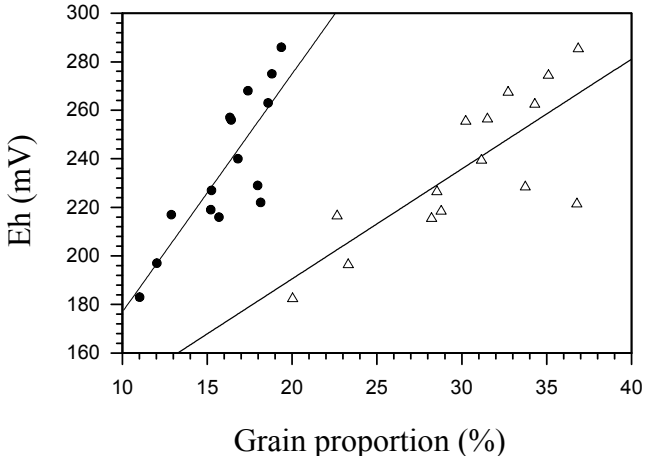


Figure 4.6: Correlations between the proportion of clay and fine silts and Eh ($p < 0.001$). The correlation coefficient (r) between Eh and clay is 0.83. The correlation coefficient between Eh and fine silt is 0.78. △clay and ●fine silt.

4.3 Nutrient levels in the sediments

Nutrient concentrations are presented in table 4.3. The nitrogenous oxides in this study are considered as the sum of NO_2^- and NO_3^-. The $NO_2^- + NO_3^-$ concentration varied between 0.56 and 4.50 $ug.g^{-1}$ dry weight sediment in the dry season and between 1.05 and 5.04 $\mu g.g^{-1}$ in the rainy season. The fluctuation of $NO_2^- + NO_3^-$ concentrations in the surface sediment was not apparent in the dry season. In general, $NO_2^- + NO_3^-$ concentrations decreased from GH01 to GH03 and from GH04 towards the sand flat (figure 4.7). The concentrations of $NO_2^- + NO_3^-$ were significantly different among the sites ($p < 0.001$) with the highest values found at GH01 and another peak was seen at GH04 at all depths. The concentration of $NO_2^- + NO_3^-$ tended to decrease down-core, but the differences between depths were not significant ($p > 0.05$).

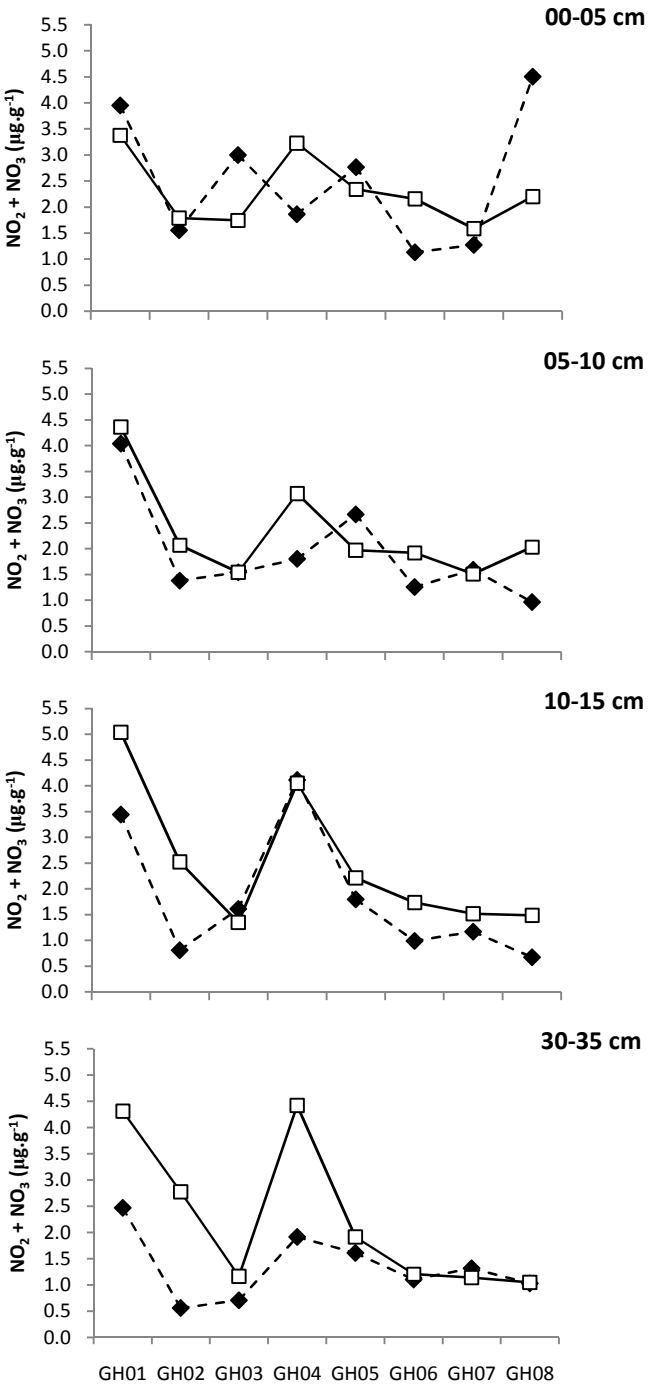


Figure 4.7: Variation of NO_2^- + NO_3^- concentration along the transect. ◆ dry season; □ rainy season

Table 4.3: Nutrient concentrations of the sediments in the dry and rainy season. The presented values are the averages of 8 sampling sites.

Content ($\mu g.g^{-1}$)	Season	00-05 cm	05-10 cm	10-15 cm	30-35 cm
$NO_2^- + NO_3^-$	Dry	2.50± 1.05	1.90 ± 0.83	1.82 ± 1.07	1.34 ± 0.53
	Rainy	2.30 ± 0.56	2.31 ± 0.80	2.49 ± 1.13	2.25 ± 1.19
NH_4^+	Dry	7.72 ± 2.20	7.39 ± 2.07	7.00 ± 2.86	6.54 ± 1.81
	Rainy	9.61 ± 2.91	8.55 ± 2.64	8.60 ± 2.35	7.53 ± 2.14
AP	Dry	13.31 ± 1.24	13.21 ± 2.09	12.20 ± 2.21	14.51 ± 2.80
	Rainy	12.85 ± 3.17	12.23 ± 2.93	12.12 ± 2.25	13.35 ± 3.08

The range of NH_4^+ concentration was from 3.71 to 15.04 and from 3.74 to 14.66 $\mu g.g^{-1}$ in the dry and rainy season, respectively. Sediment depth, season and location of the sampling sites are the factors that significantly controlled the NH_4^+ concentration (table 4.2). The concentrations of NH_4^+ decreased gradually with depth, consistent with aeration of the deep sediments. The NH_4^+ concentrations were significantly higher in the rainy season (table 4.2). No apparent tendency of NH_4^+ concentration fluctuation was found through the landscapes in the surface sediments. However, in the layers beneath 5 cm, the NH_4^+ concentration seemed to increase towards the more tidally affected sites (figure 4.8). NH_4^+ seemed to be more dominant than NO_2^- and NO_3^-. The NH_4^+ to (NO_2^- + NO_3^-) ratio varied between 0.8 and 12.9 during the sampling year.

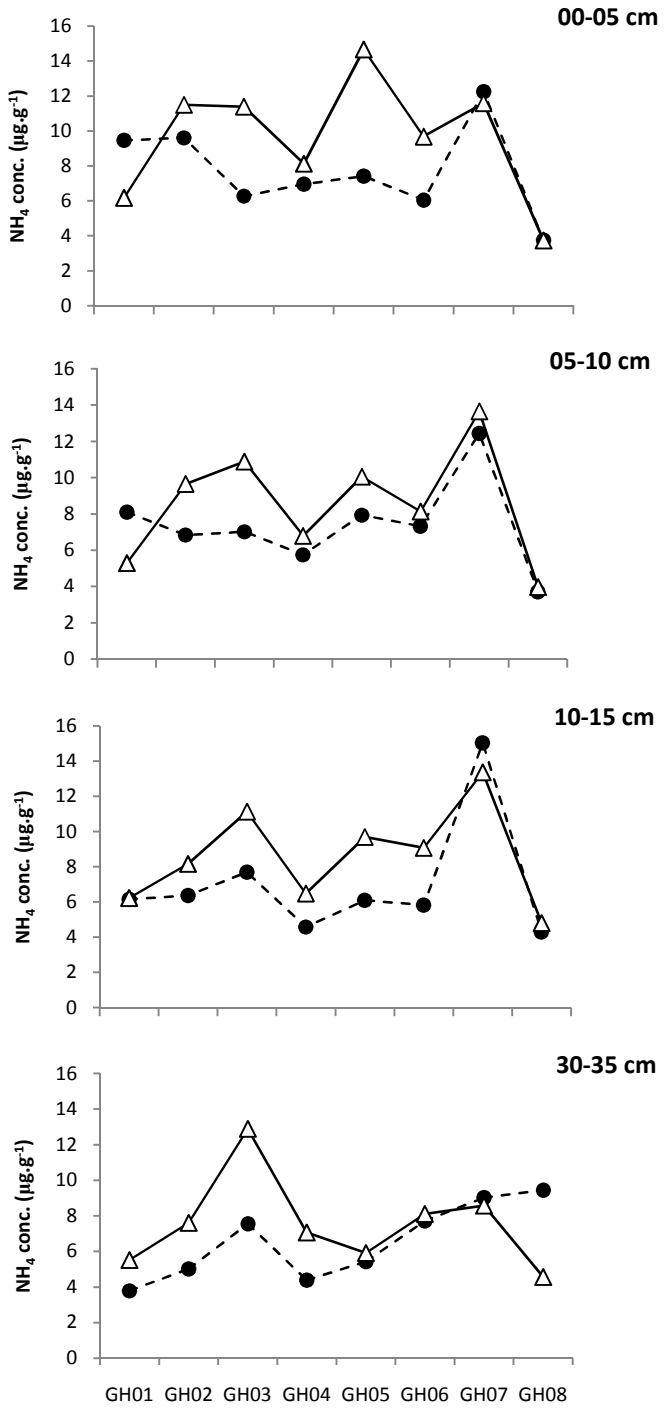


Figure 4.8: Variation of NH_4^+ concentration along the transect. ●dry season; △ rainy season.

The range of AP varied from 7.50 to 21.04 $\mu g.g^{-1}$ in the dry season, and from 4.01 to 19.35 $\mu g.g^{-1}$ in the rainy season. There was no significant difference in AP concentrations between the dry and rainy season, or among the sampling depths (table 4.2). It was even not revealed in a specific trend down-core. Within the 0-15 cm sediment interval, AP concentration seemed to increase towards the more tidally affected sites. However, the highest concentration of AP occurred at the dwarf black mangrove (GH04), where the sediment was extremely dry and saline while the lowest values was found at the sand flat (figure 4.9). Nevertheless, in the depth of 30-35 cm, the peaks of AP concentration were found at the creek (GH03) and the mangrove fringe (GH06) in the rainy season (figure 4.9).

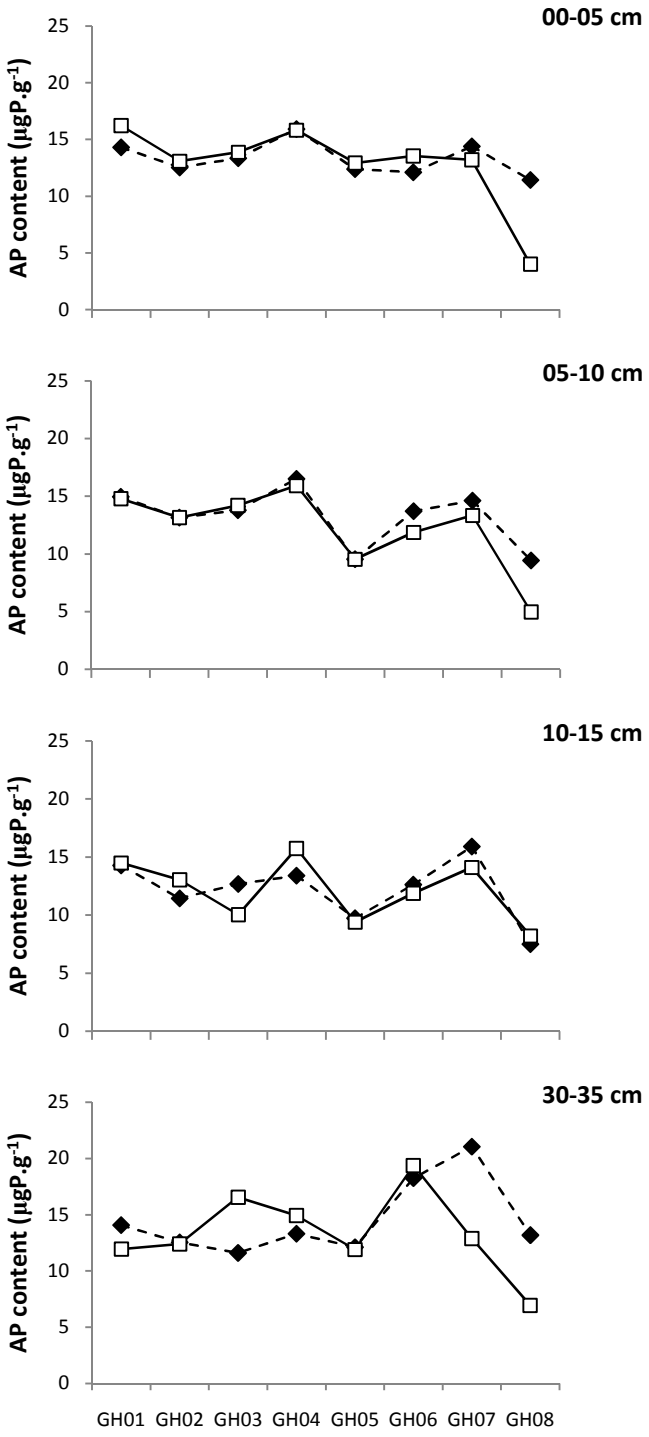


Figure 4.9: The variation of AP concentration along the transect. ◆dry season; □ rainy season.

4.4 Elemental composition in the sediments

The level of OC and TN at sites occupied by *Sesuvium portulacastrum* (including GH01 and GH02), which will be referred to "Sea purslane sites" in the following, were significantly higher than in the area of pure mangrove stands ($p < 0.05$ and 0.01, for the difference in OC and TN level, respectively). Nevertheless, these differences were found exclusively in the surface sediment in the dry season (figure 4.10). The quantity of OC and TN decreased from the vegetated sites towards the sea (figure 4.11) and the values at the sand flat (GH08) were significantly lower than the other sampling sites (table 4.2). The levels of OC and TN tended to decrease down-core within the 0-15 cm interval during the sampling year (figure 4.11). A negligible increase of these properties was seen at the depth of 30-35 cm, but no significant difference between the studied depths was recorded (table 4.2). The sediment depth, season and location of the sampling sites controlled the quantity of OC and TN in the sediments (table 4.2).

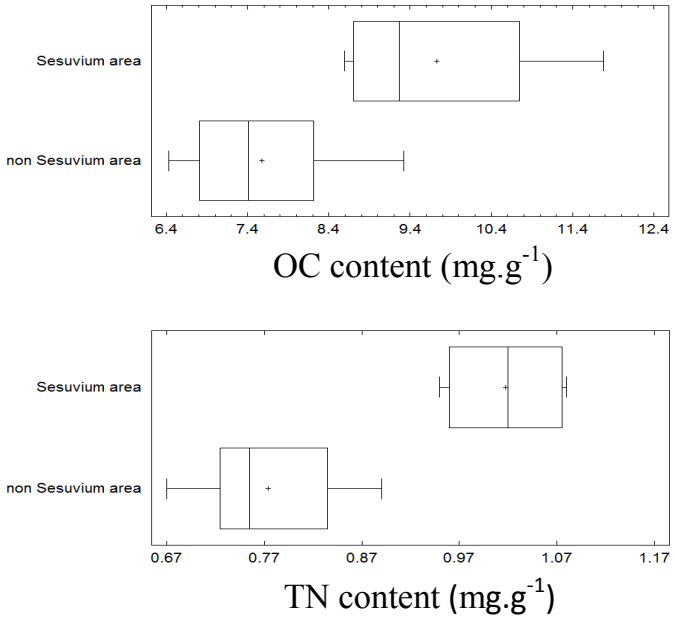


Figure 4.10: Differences in OC and TN levels in surface sediments of the areas occupied by *Sesuvium portulacastrum* and pure mangrove stands in the dry season.

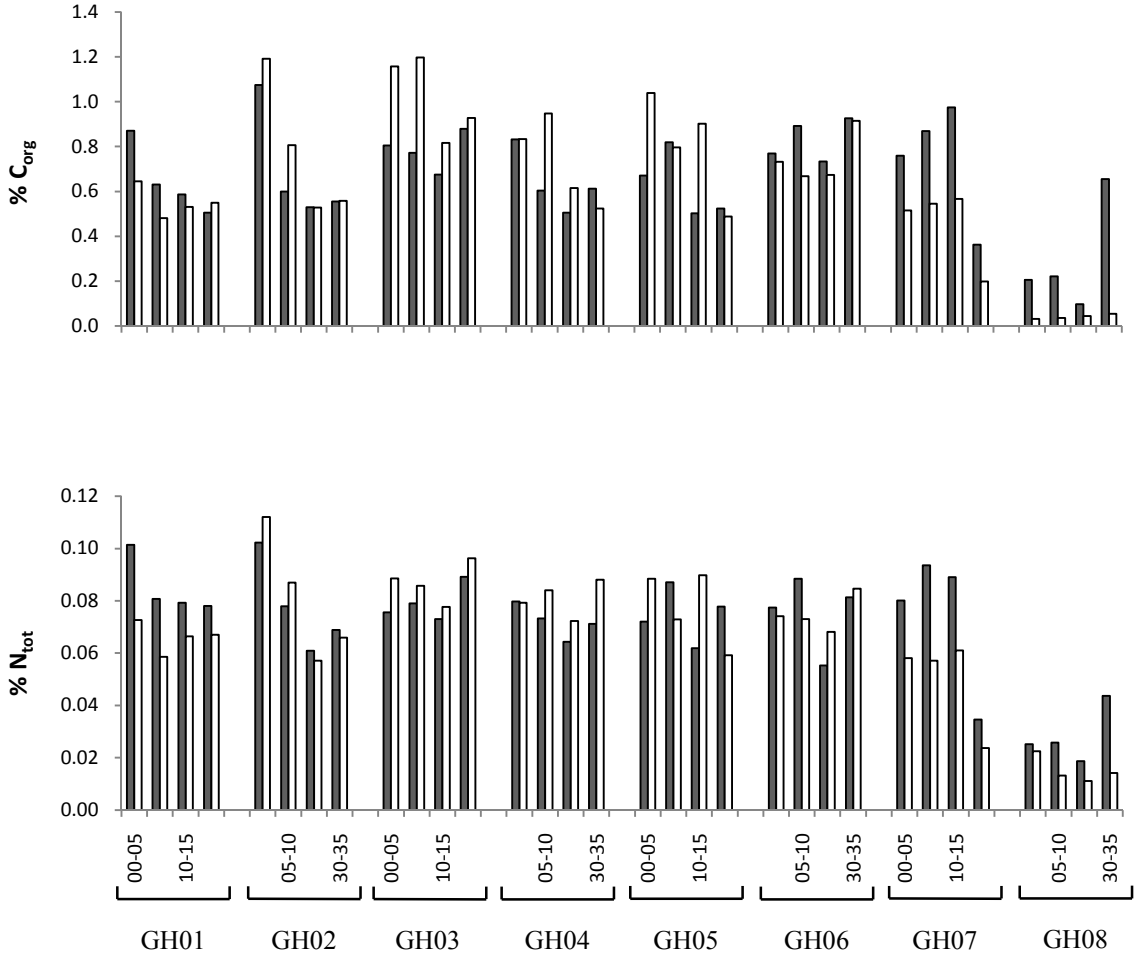


Figure 4.11: Down-core variation of OC and TN along the transect. ■ dry season, □ rainy season.

4.5 Fractions of IP and OP in the sediments

The TP content varied from 400.6 to 968.9 $\mu g.g^{-1}$ in the dry season and from 369.9 to 771.4 $\mu g.g^{-1}$ in the rainy season. IP was the major contributor to sedimentary P pool. The average IP:TP ratio in the sediment was 92.8 and 94.1% in the dry and rainy season, respectively.

There were significant differences in TP and IP contents between the four investigated depths ($p < 0.01$), but there was no consistent trend of down-core variation among the sampling sites. The quantities of TP and IP decreased continuously down-core at GH04, GH05, GH06 and GH08 (figure 4.12 and 4.13). No seasonal influence on TP and IP contents was found in the sampling year (table 4.2). Within the 0-10 cm interval, the content of IP increased from GH01 to GH05 then decreased gradually to GH07 and reached another peak at the sand flat (GH08). The variation of IP in 10-15 cm was negligible but in the layer of 30-35 cm, IP content tended to decrease towards the sea (figure 4.13).

In the whole study area, the level of OP in the dry season was significantly higher as compared to the rainy season ($p < 0.01$). No significant difference in OP content between depths was found in the sampling year (table 4.2). The level of OP was highest at the mix stand of *Avicennia* and *Sesuvium* (GH02) (figure 4.14), but no significant difference was found in the group of the other sites.

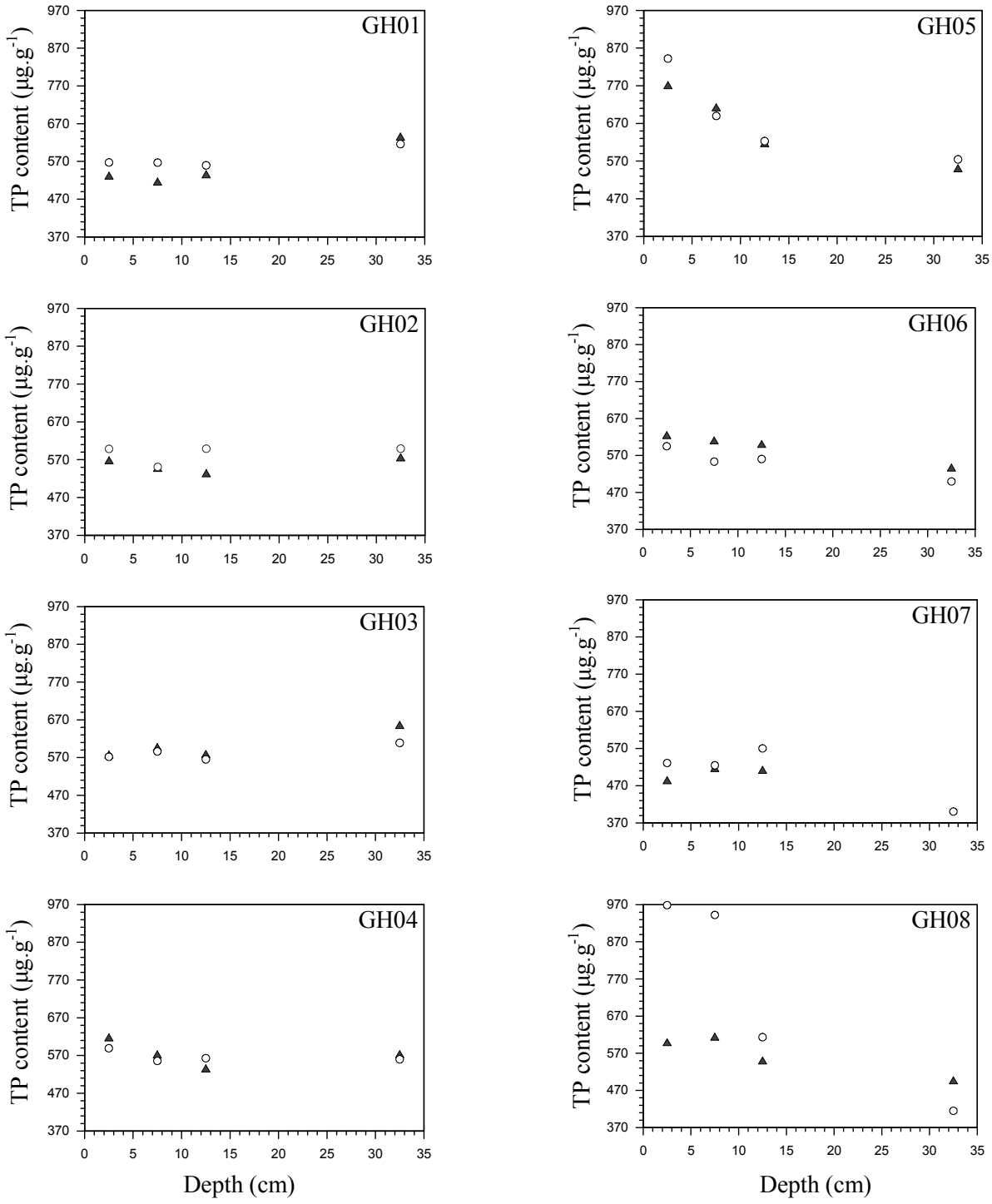


Figure 4.12: Down-core variation of TP content (µg.g^{-1}) at each sampling site during the sampling year. ○ dry, ▲ rainy season.

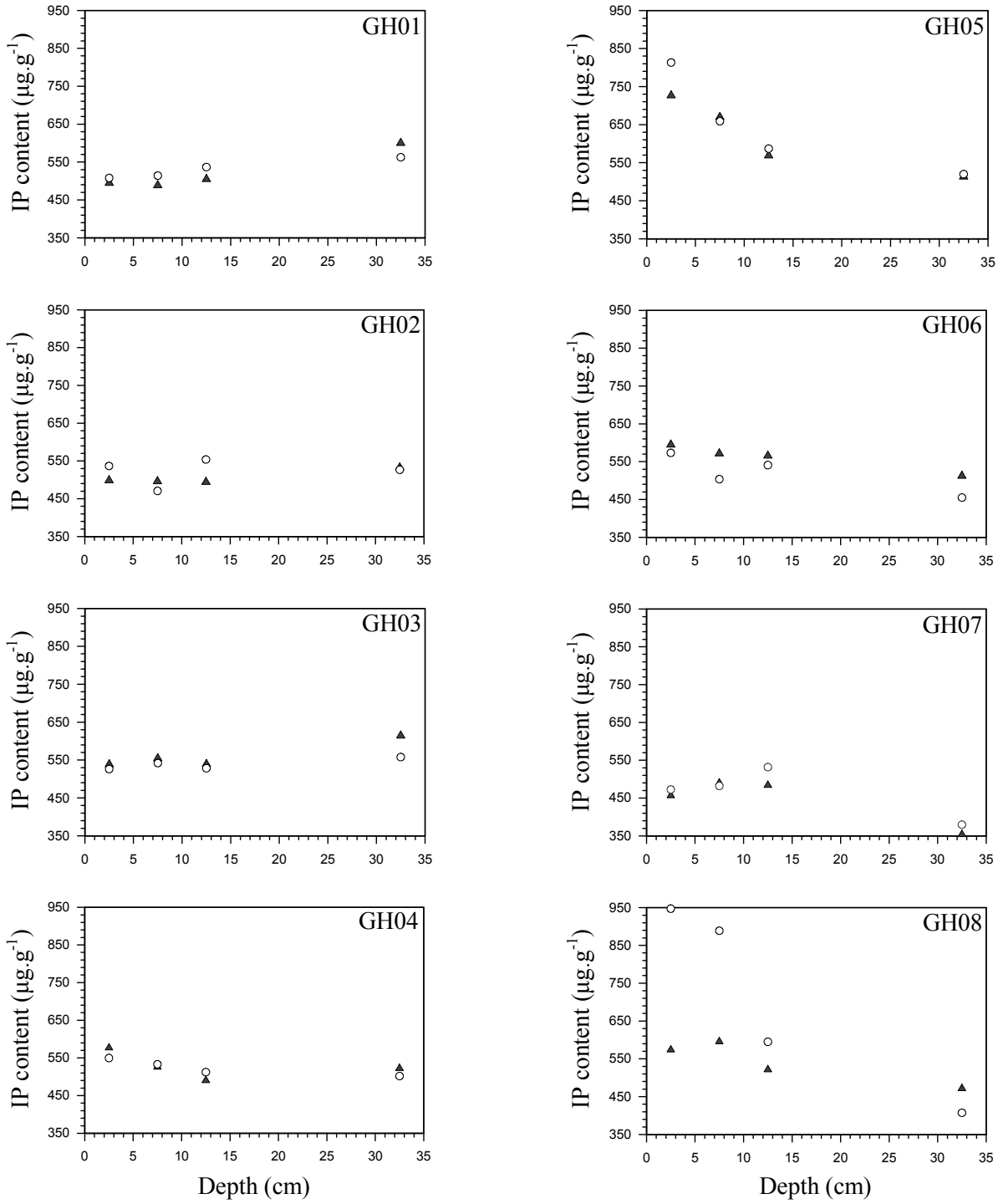


Figure 4.13: Down-core variation of IP content (µg.g^{-1}) at each sampling site during the sampling year. ○ dry, ▲ rainy season.

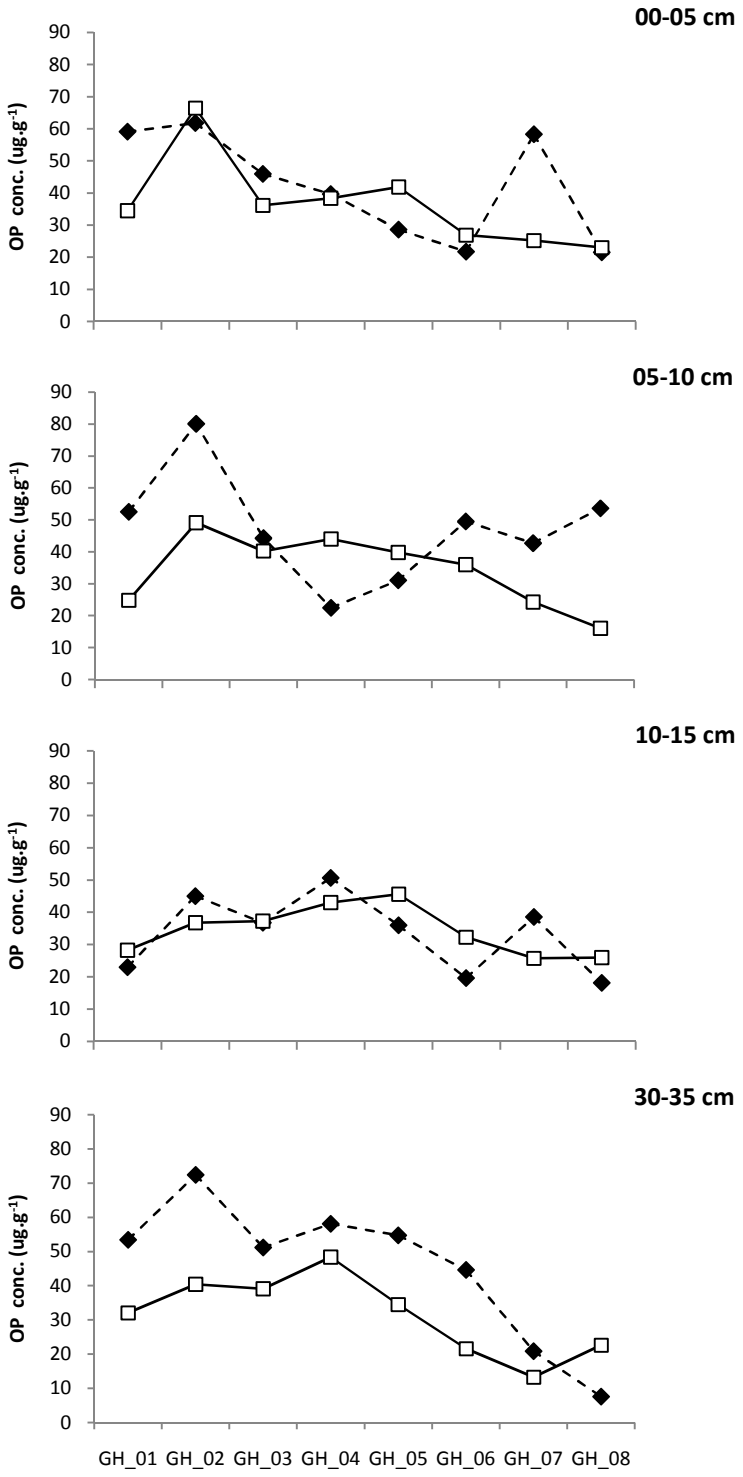


Figure 4.14: Variation of OP content in each depth along the transect. ◆dry, □ rainy season.

On average, AP accounted for 2.54 and 2.39 % of the IP in the dry and rainy season, respectively. Although P solubilization tended to be more effective in the dry season, the difference is not significant ($p > 0.05$). The down-core variation of AP:IP ratio within 0-15 cm was negligible (figure 4.15), but it was significantly higher in 30-35 cm ($p < 0.05$). The values of AP:IP ratio fluctuated between 2.4 and 2.9% at GH01, GH02, GH03, GH04 and GH06 indicating a similar rate of P solubilization in these sediments. The lowest ratios were found at GH05 and GH08 (figure 4.15), probably due to the high pH which resulted from the abundance of carbonate in these sediments. The remarkable high values of AP:IP ratio was acquired at GH06 and GH07 in 30-35 cm (figure 4.15). There was no consistent trend of down-core variation in IP:OP ratio (figure 4.16). The IP:OP ratio was higher in the rainy season as compared to the dry season, but the difference was not significant ($p > 0.05$).

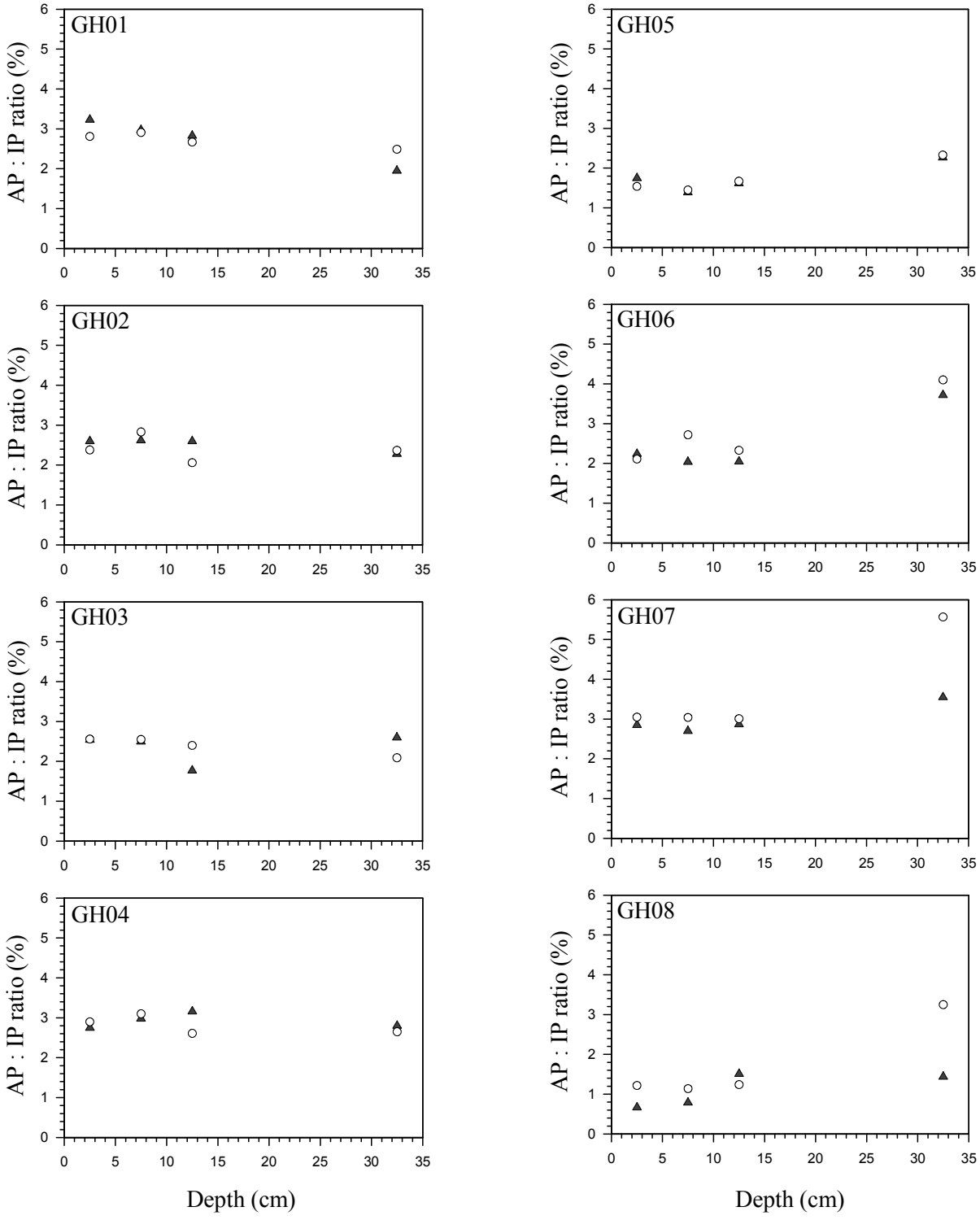


Figure 4.15: Down-core variation of AP:IP ratio at each sampling site during the sampling year. ○ dry, ▲ rainy season.

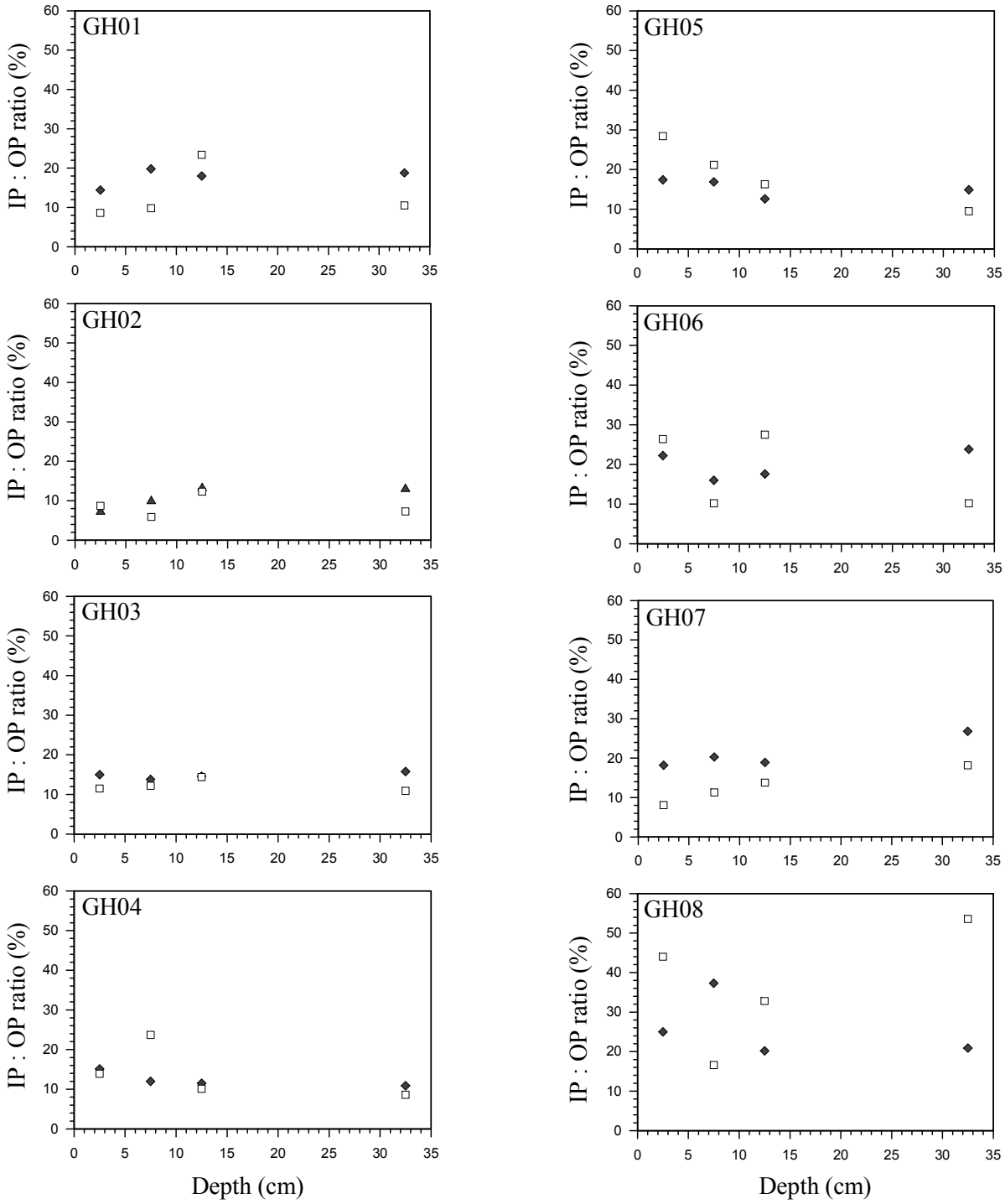


Figure 4.16: Down-core variation of IP:OP ratio at each sampling site during the sampling year. □ dry, ◆ rainy season.

4.6 Chitin

4.6.1 Kinetics experiments

The first calibration point did not contain any chitin flake. Consequently, its fluorescence intensity was the highest. However, the decrease of fluorescence intensity with the increasing of chitin concentration was not linear for the calibration (figure 4.17). The figure 4.17 shows that each concentration of the calibration express the different fluorescence intensity in the duplication .The variability of calibration values, especially the wide variation range of the blank after 16 hours of incubation (table 4.4), suggested that the incubation during sixteen hours might affect the stability of FITC-WGA in the phosphate buffer.

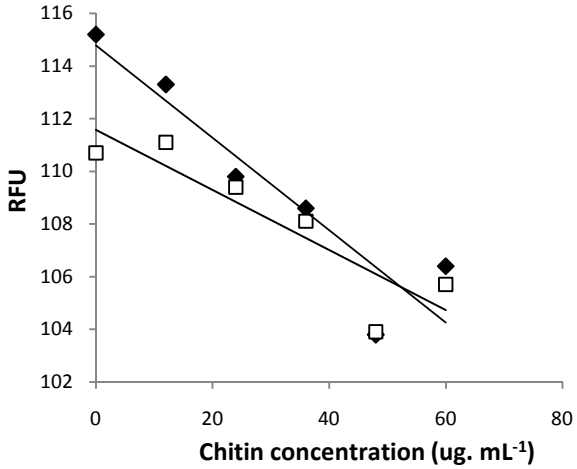


Figure 4.17: Duplicate calibration of chitin incubated for 16 hours at 30°C. ◆first, □second calibration. The slope and coefficient correlation from the first calibration are -0.175 and 0.92, respectively. The slope and coefficient correlation from the second calibration are -0.114 and 0.90, respectively.

Table 4.4: The sixteen-hour incubation calibrations. The calibration was repeated for 6 times.

Chitin concentration (ug/mL)	RFU_Ex 426, Em 520, V 510					
0	165.4	165.0	115.2	110.7	126.5	128.3
12	176.5	174.4	113.3	111.1	126.2	127.5
24	174.6	189.0	109.8	109.4	124.1	127.1
36	172.5	OFL	108.6	108.1	121.8	123.8
48	154.1	157.4	103.8	103.9	121.2	122.3
60	160.9	173.1	106.4	105.7		

The kinetics was set up for the blank and the fourth calibration point (36 µg chitin. mL^{-1}) with different incubation time. The fluorescent intensity of the blank and the calibration point were measured at 15, 30, 60, 120, 180, 240 and 300 minutes. The fluorescent units of the blanks changed quickly within the 180 first minutes but seemed to become stable afterwards (table 4.5). The fluorescence units of the duplicated blank were different from each other within 15 and 60 minutes, indicating that this period was not long enough for FITC-WGA to reach the stable state (table 4.5). The fluorescence units of the calibration point reached the stable state also after 180 minutes and the stability lasted until the minute 240 (table 4.6). The increase of the fluorescence units after 240 minutes may indicate liberation of FITC-WGA from the complex chitin-FITC-WGA. The kinetics of the blank and fourth calibration point suggest that 240 minutes can be the appropriate time for chitin incubation in the phosphate buffer with 2 mL FITC-WGA.

Table 4.5: The kinetics experiment of the blank (5 mL phosphate buffer + 2 mL FITC-labeled WGA)

Minute	RFU1	RFU2
15	111.9	112.7
30	110.7	112.1
60	111.4	112.0
120	110.9	111.2
180	109.2	109.5
240	109.8	110.5
300	108.6	109.6

The kinetics of sediment indicated that 240 minutes is also the sufficient time for the incubation of sediment samples (table 4.7). The difference between the duplicated calibrations during 3, 4 and 5 hours are presented in figure 4.18. The highest slope and correlation coefficients, associated with the stable intercepts of the four-hour incubation as compare to three- and five-hour incubation, result in the application of 4 hours for the incubation of all sediment samples.

Table 4.6: The kinetics experiment of the fourth calibration point (180 μg chitin in 5 mL phosphate buffer + 2 mL FITC-labeled WGA)

Minute	RFU
15	114.5
30	112.4
60	111.2
120	109.9
180	108.8
240	108.3
300	109.5

Table 4.7: The kinetics experiment of 10 mg sediment incubated at room temperature in 5 mL phosphate buffer and 2 mL FITC-WGA.

Minute	RFUt	RFUs
15	113.3	9.1
30	111.5	9.5
60	111.8	10.4
120	111.2	10.8
180	108.8	10.9
240	108.8	10.8
300	106.9	12.5

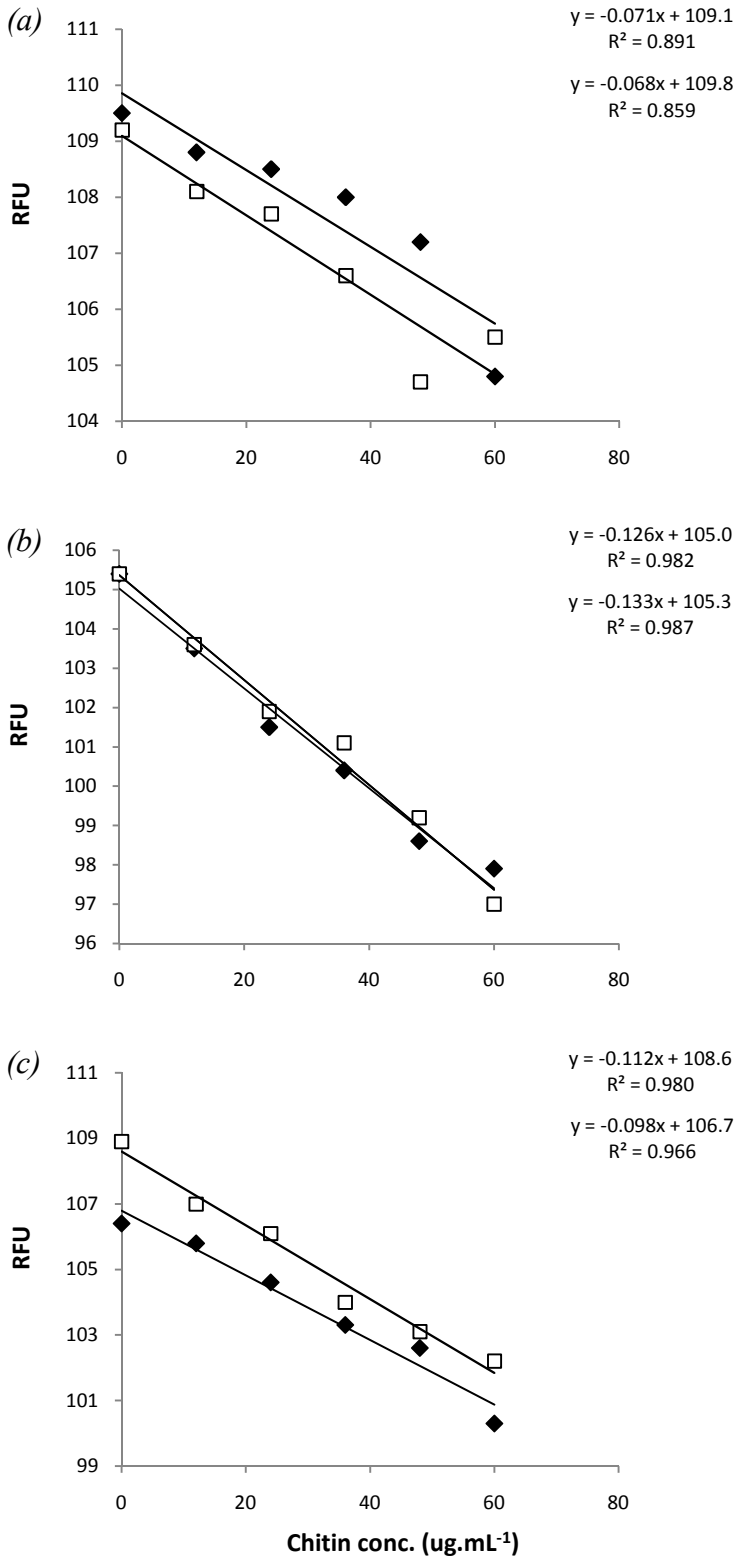


Figure 4.18: Comparison of calibration curves from the incubation during (a): 3 hours, (b): 4 hours and (c): 5 hours

4.6.2 Chitin quantity in the sediment

The chitin quantity in the sediments varied between 10.2 and 77.2 $mg.g^{-1}$ in the sampling year. The mean concentration of chitin in the dry and rainy season was 46.2 and 47.5 $mg.g^{-1}$, respectively. No significant difference in chitin concentration was found between depths ($p > 0.05$) and the down-core variations were not consistent through the landscapes (figure 4.19). The highest quantities of chitin were usually found in 30-35 cm (figure 4.19).

The concentration of chitin apparently decreased towards the tidal flat and this tendency was identical in all depths during the sampling year (figure 4.19). The decrease from GH06 to GH08 was comparable for all depths in the dry as well as rainy season. The chitin quantities were significant lower at the more alkaline sites, including GH05, GH07 and GH08 ($p < 0.001$), but the difference between the other sites was negligible. There was no significant seasonal difference in the chitin contents ($p > 0.05$).

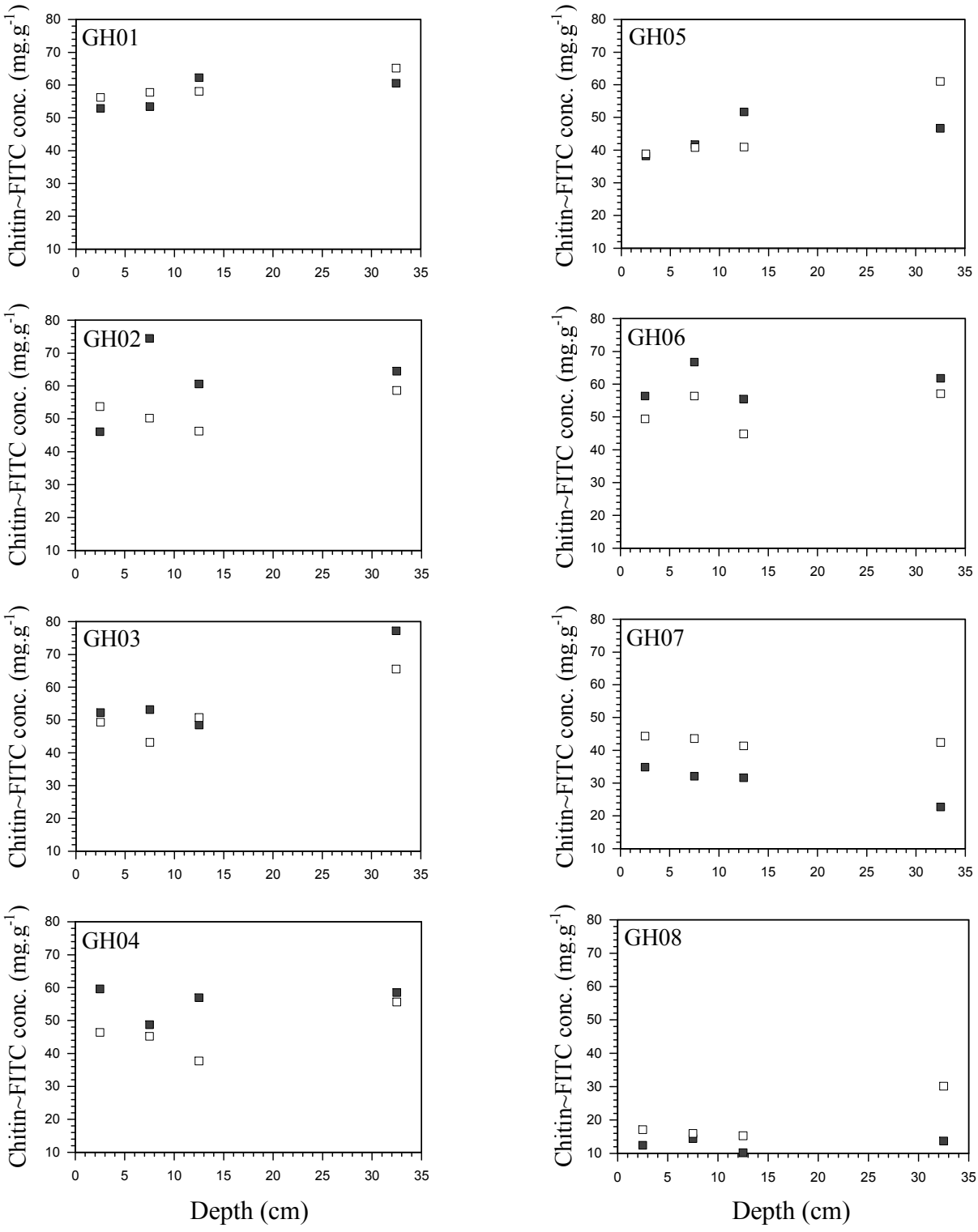


Figure 4.19: Down-core variation of the chitin concentration at each site. □dry, ■ rainy season, respectively.

4.7 Amino acids and amino sugars in the sediment

4.7.1 Amino acids

The content of total hydrolysable amino acids (THAA) was calculated by the sum of proteinaceous and non-proteinaceous amino acids in the sediments. The THAA content varied from 0.28 to 2.95 $mg.g^{-1}$ in the dry season and from 0.20 to 3.12 $mg.g^{-1}$ in the rainy season. The down-core decreases in THAA content were found at most of the sampling sites during the sampling year with disturbances in the rainy season which probably resulted from dwelling-organisms (figure 4.20), but sediment depth was not the factor influencing the THAA content ($p > 0.05$). In the surface sediments (0-5 cm), the content of THAA drastically increased from GH01 to GH02 (*ca.* 36 % in the dry season and 50 % in the rainy season) and tended to decrease towards the sea in both sampling seasons (figure 4.21). On the contrary, within 5-15 cm, in the dry season, the THAA content increased seaward and the peak was found at the mud flat (GH07) (figure 4.21). In the rainy season, the THAA content decreased from GH03 to GH06 in 5-10 cm. The THAA fluctuation through the ecotones was not apparent in the deeper sediments, but the lowest content of THAA was found always at the sand flat (GH08) (figure 4.21), corresponding with the lowest content of OC and TN in this sediment (figure 4.11).

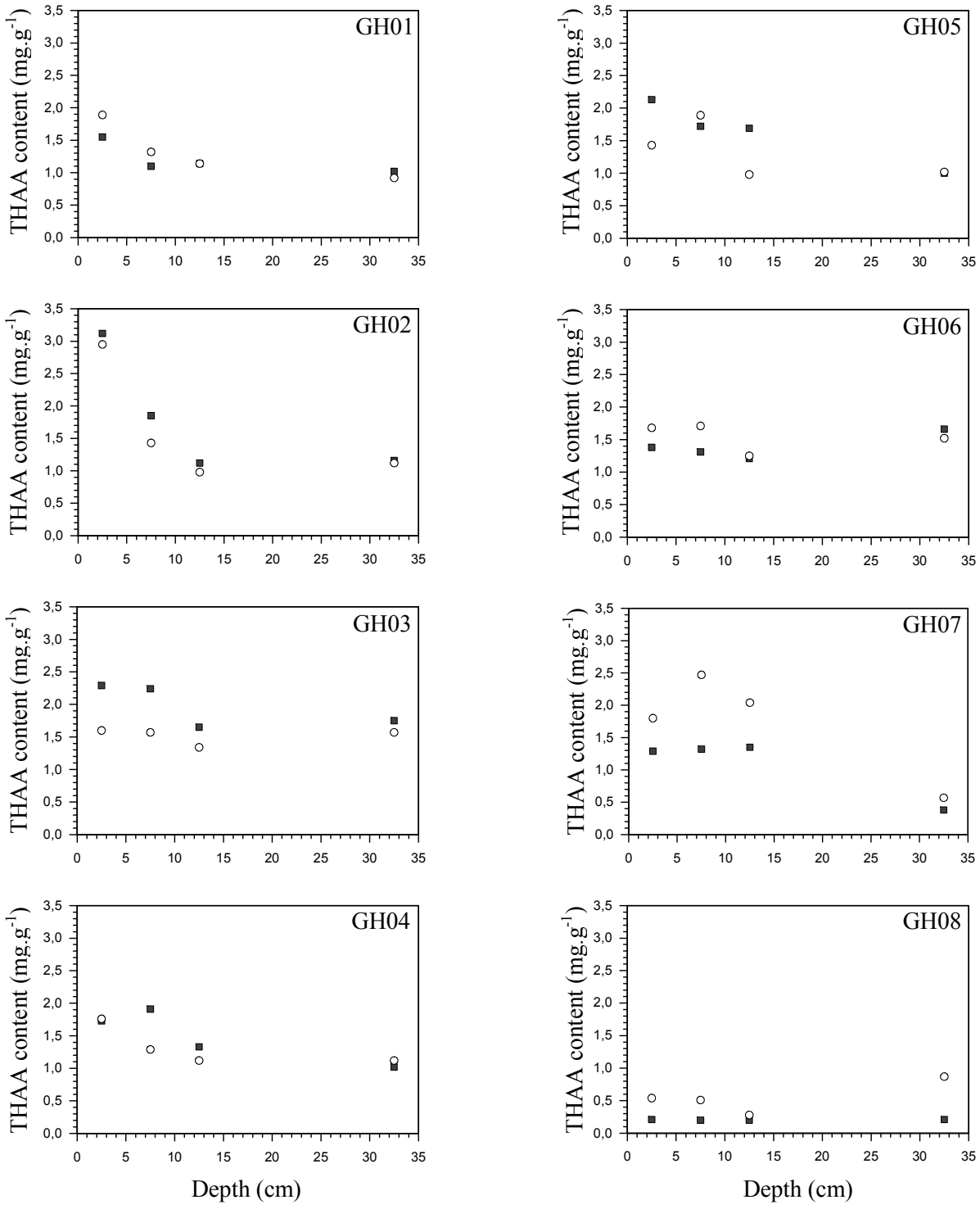


Figure 4.20: Down-core variation of THAA content at each sampling site. ○ dry, ■ rainy season.

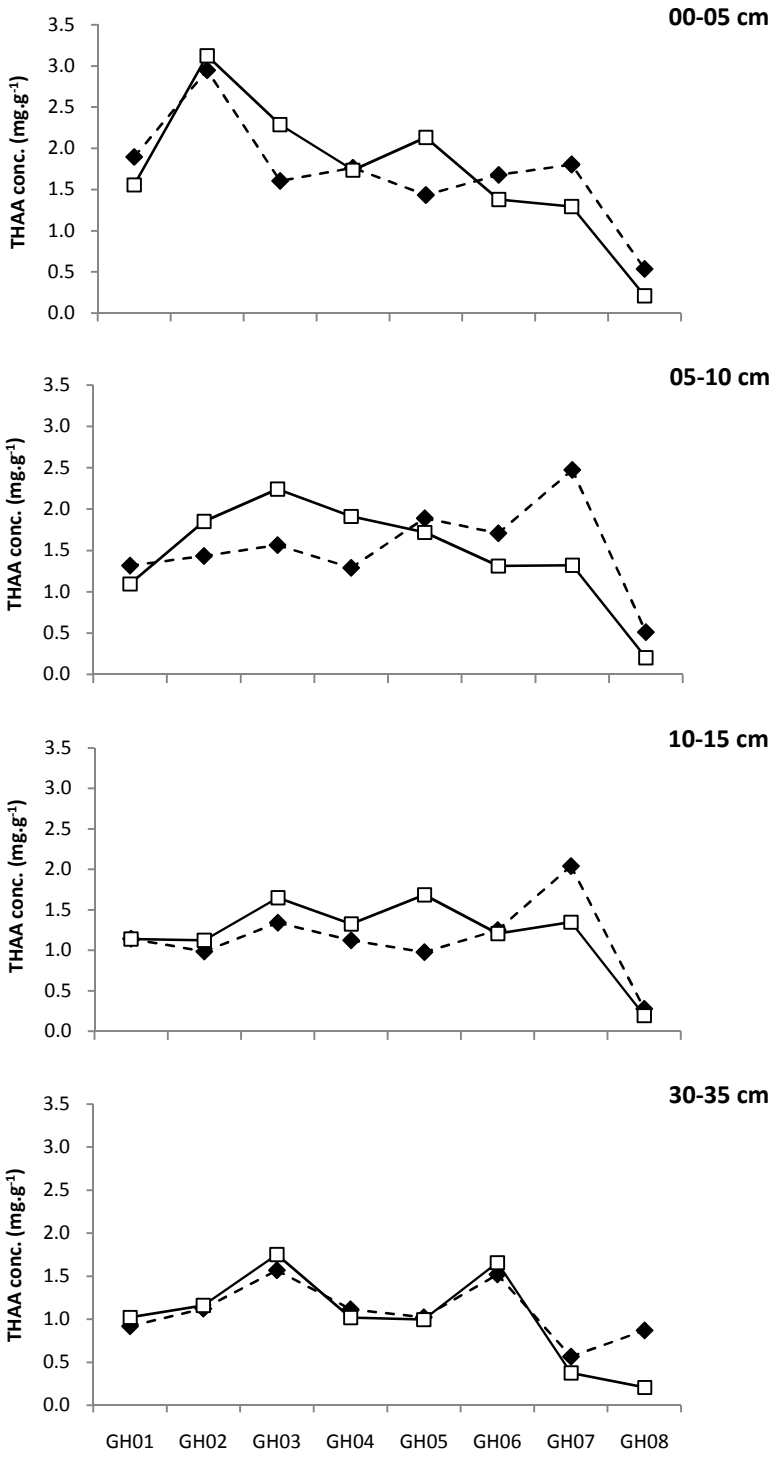


Figure 4.21: Variation of THAA content along the transect at each depth. ◆dry, □rainy season.

Nitrogen in the THAA (N_{aa}) accounted for 25.5 and 27 % of the N pool in the dry and rainy season, respectively. OC in the THAA (C_{aa}) averaged 8.8 and 10.7 % of the total sedimentary OC in the dry and rainy season, respectively. The N_{aa}:TN ratio significantly decreased down-core in the sampling year ($p < 0.01$) (figure 4.22) while the significant decrease in C_{aa}:OC ratio was just found in the dry season (figure 4.23). However, the increases at 5-10 cm of the C_{aa}:OC ratio were found at GH03, GH05 and GH07 in both seasons (figure 4.23). A similar finding in N_{aa}:TN ratio was seen at GH05 and GH07 in the dry season (figure 4.22).

The total contribution of THAA to the pool of OC at GH08 was drastically higher than the other sites in the rainy season (approximately 60 % within 0-10 cm and 45 % in the deeper layers) (figure 4.23). Although there was not a significant difference in C_{aa}:OC ratio from GH01 to GH07, it seemed to be higher at GH02 and GH07.

In the rainy season, the N_{aa}:TN ratio tended to decrease from GH03 to GH06 within 0-15 cm (figure 4.22). The tendency was not clear in the dry season. The ratio consistently increased from GH01 to GH03 in all depths. The highest ratios were found at GH03, GH07 within 5-15 cm and at GH03, GH06 in 30-35 cm. In the surface sediments, the peaks were acquired at GH02 and GH08 (figure 4.22). In general, the N_{aa}:TN ratios were significantly different between the sampling sites ($p < 0.05$). The mean ratio was higher in the rainy season, but the difference was not significant ($p > 0.05$).

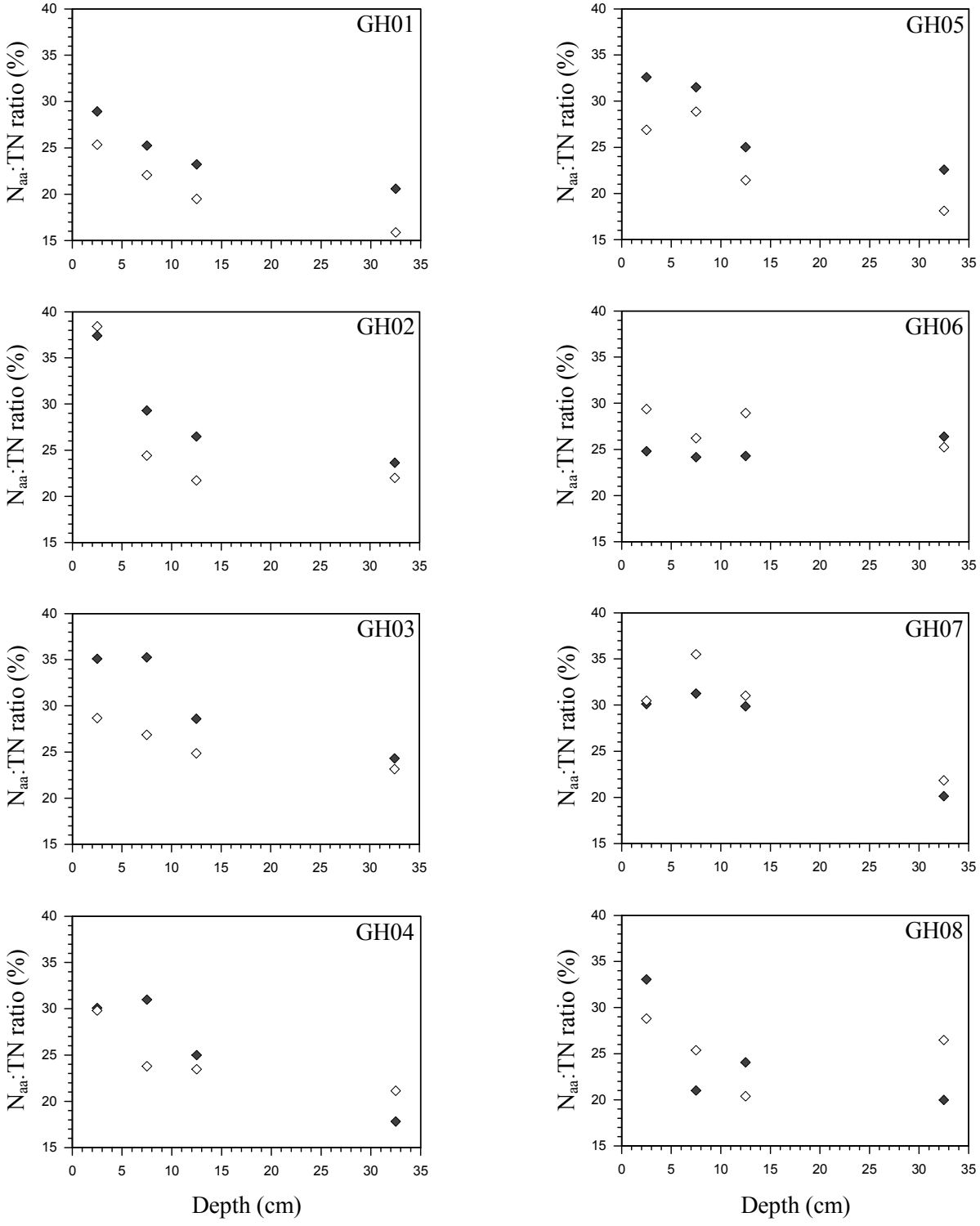


Figure 4.22: Down-core variation of N_{aa}:TN ratio in the sediments. ◇dry, ◆rainy season.

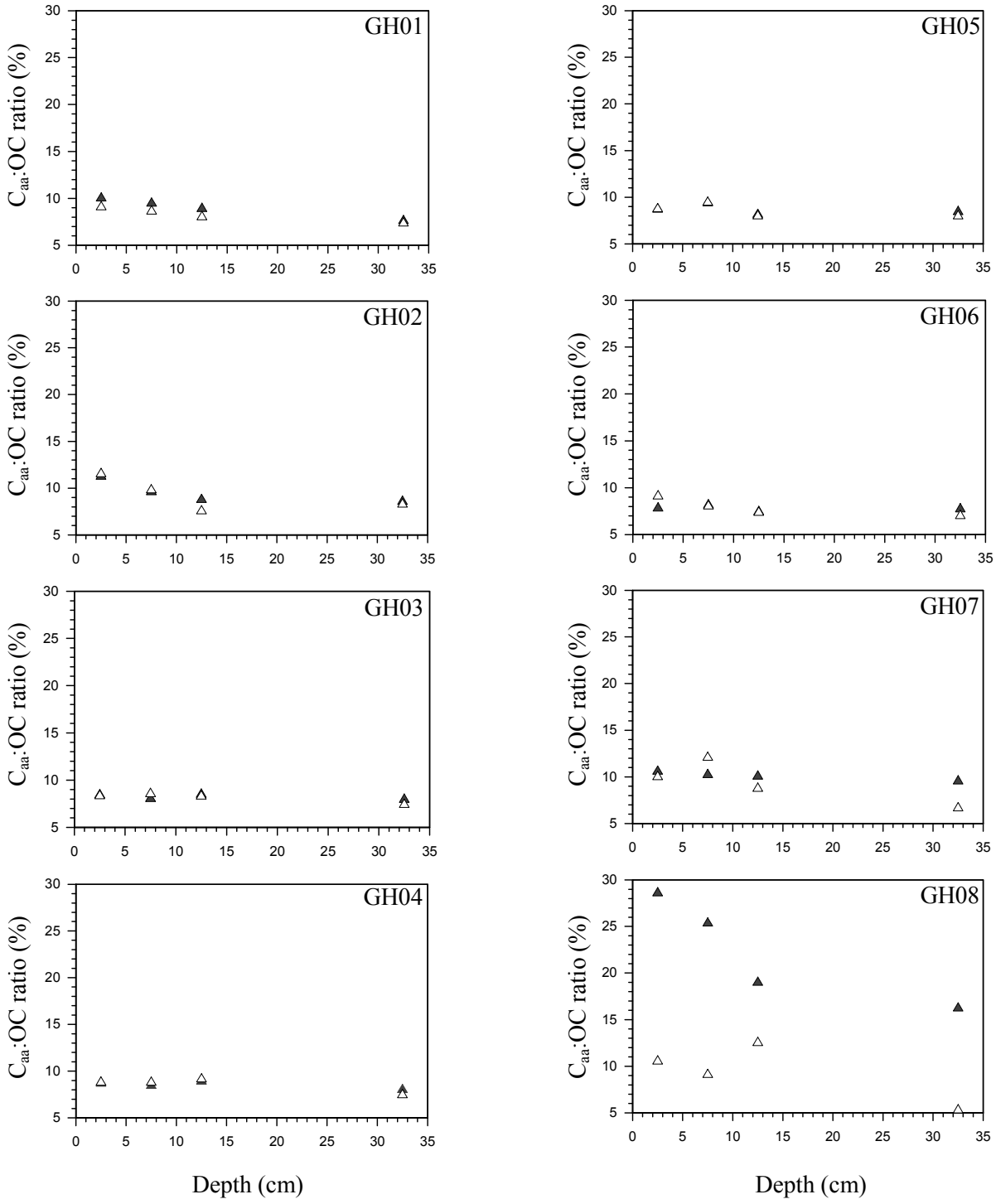


Figure 4.23: Down-core variation of C_{aa}:OC ratio in the sediments. △dry, ▲ rainy season.

Neutral amino acids were the most dominant group in Ganh Hao in the sampling year. The relative abundance of the amino acid groups followed the order: neutral > acidic > basic > aromatic > sulfur-containing > non-protein (figure 4.24). The relative abundance pattern of the amino acid groups was not affected by either season or depth in the sediments.

The neutral group accounted for more than 50% of the THAAs. Consequently, their contributions to the pool of OC and TN in the sediments were higher than the other groups. The contribution of each amino acid group to the pool of OC and TN in the sampling year is presented in figure 4.25, 4.26, 4.27 and 4.28.

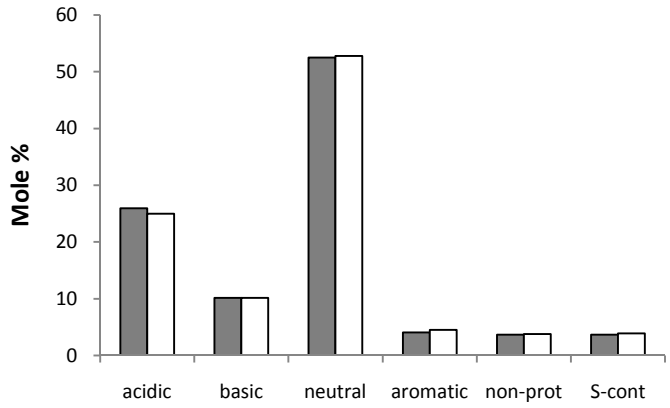


Figure 4.24: Concentration of amino acid groups in the sediment. ■ dry, □ rainy season.

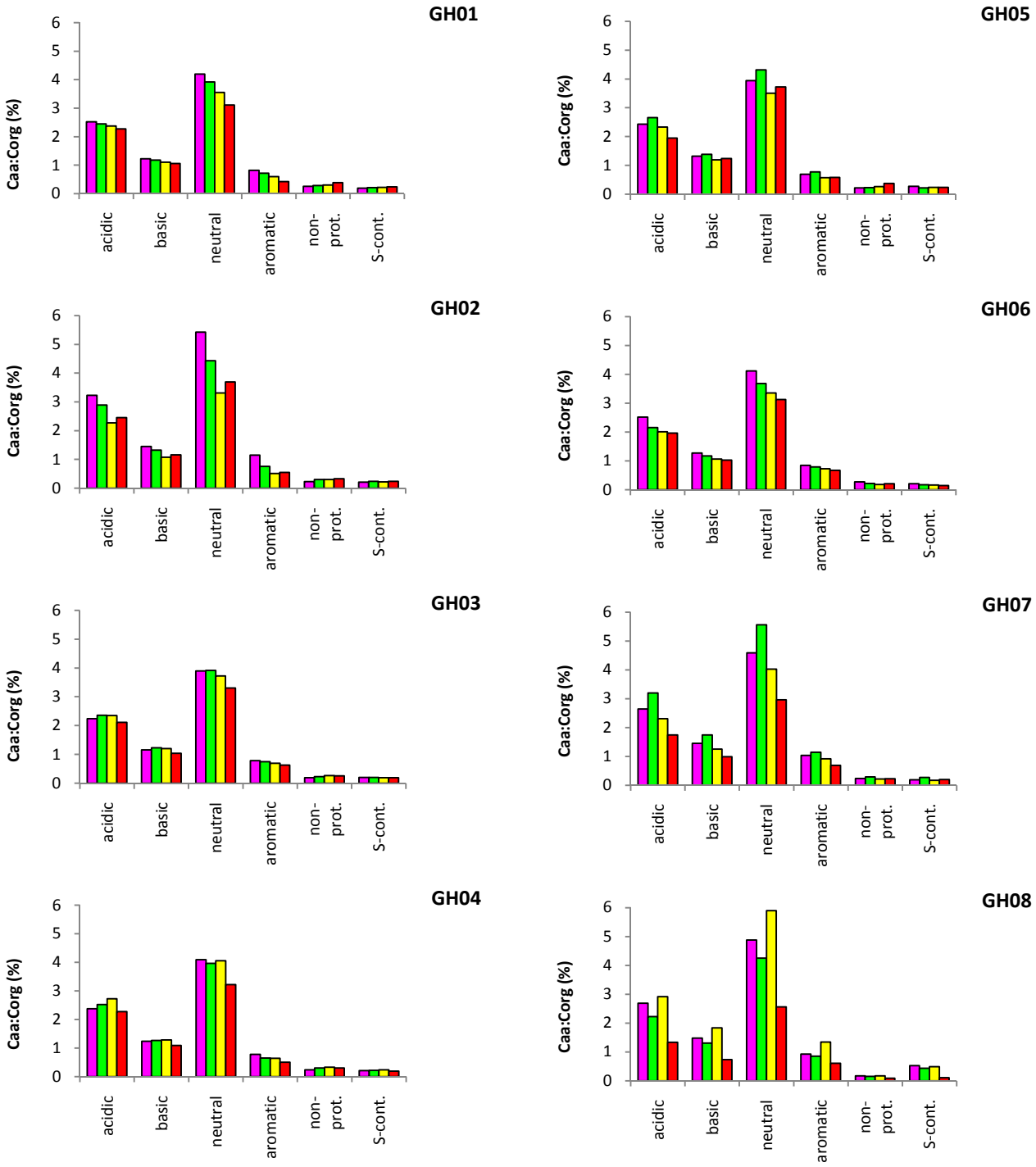


Figure 4.25: Down-core variation in contribution of each amino acid group to the pool of OC in the dry season. 0-5 cm, 5-10 cm, 0-15 cm and 30-35 cm, respectively.

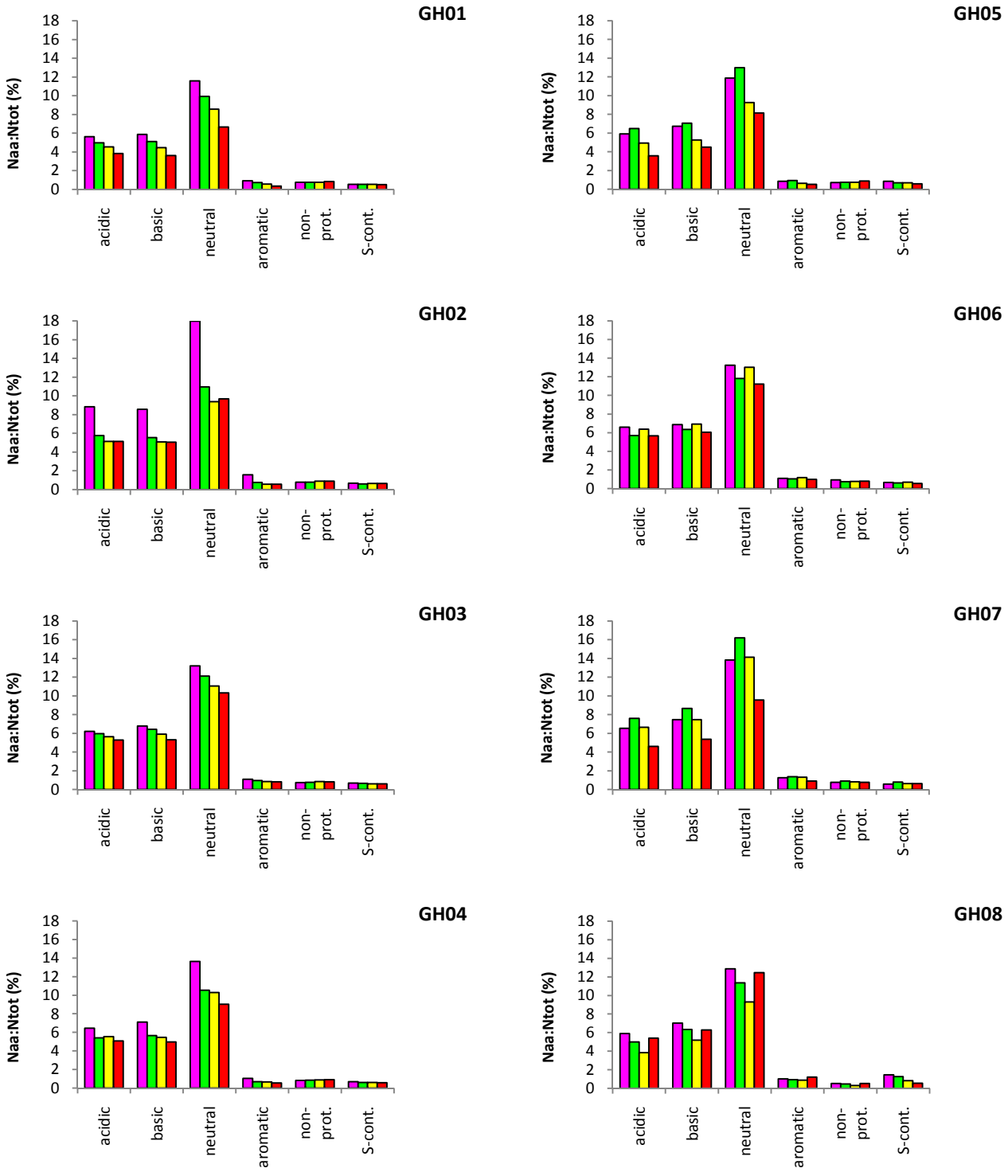


Figure 4.26: Down-core variation in contribution of each amino acid group to the pool of N in 8the dry season. 0-5 cm, 5-10 cm, 10-15 cm and 30-35 cm.

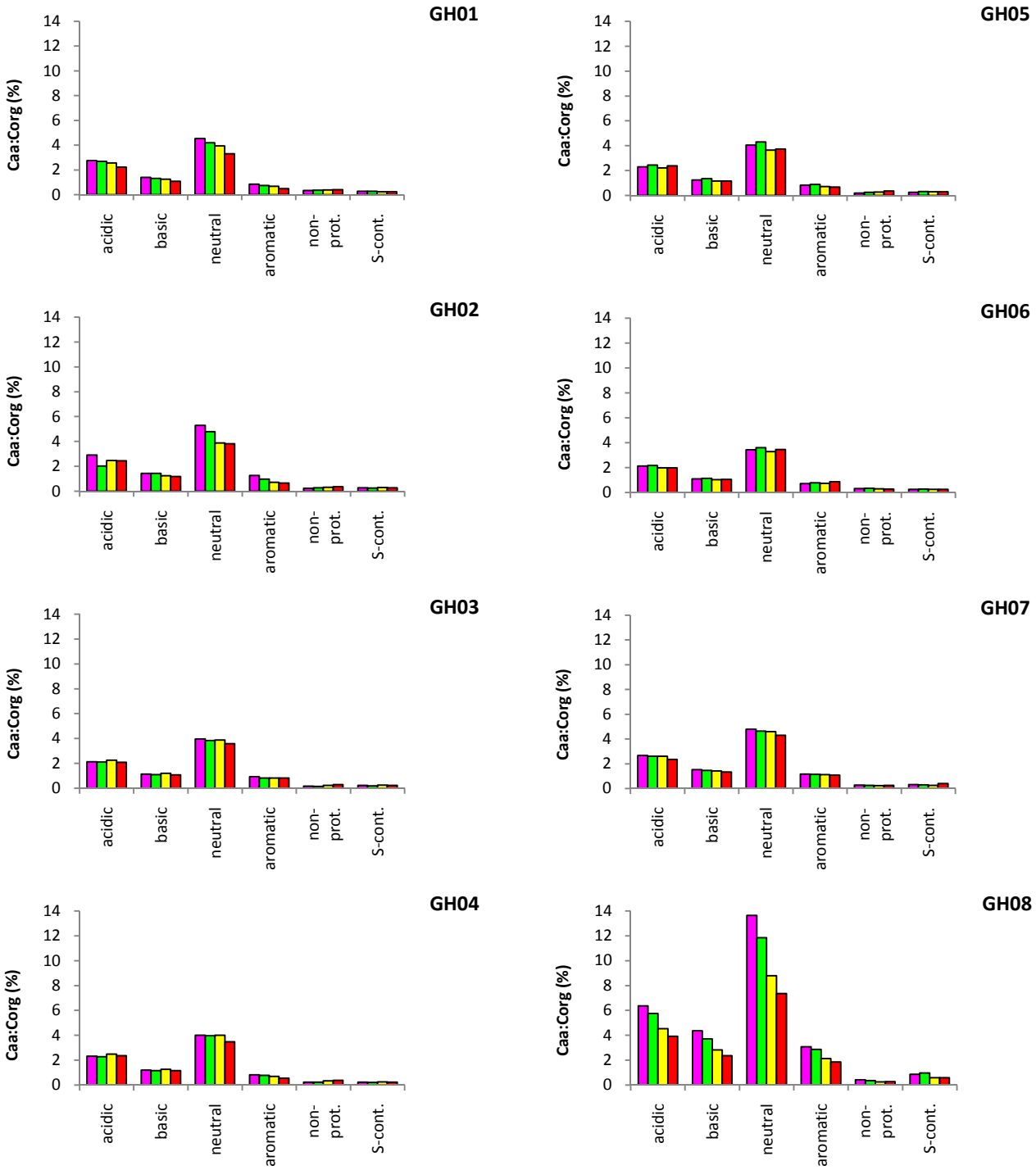


Figure 4.27: Down-core variation in contribution of each amino acid group to the pool of OC in the rainy season. 0-5 cm, 5-10 cm, 10-15 cm and 30-35 cm.

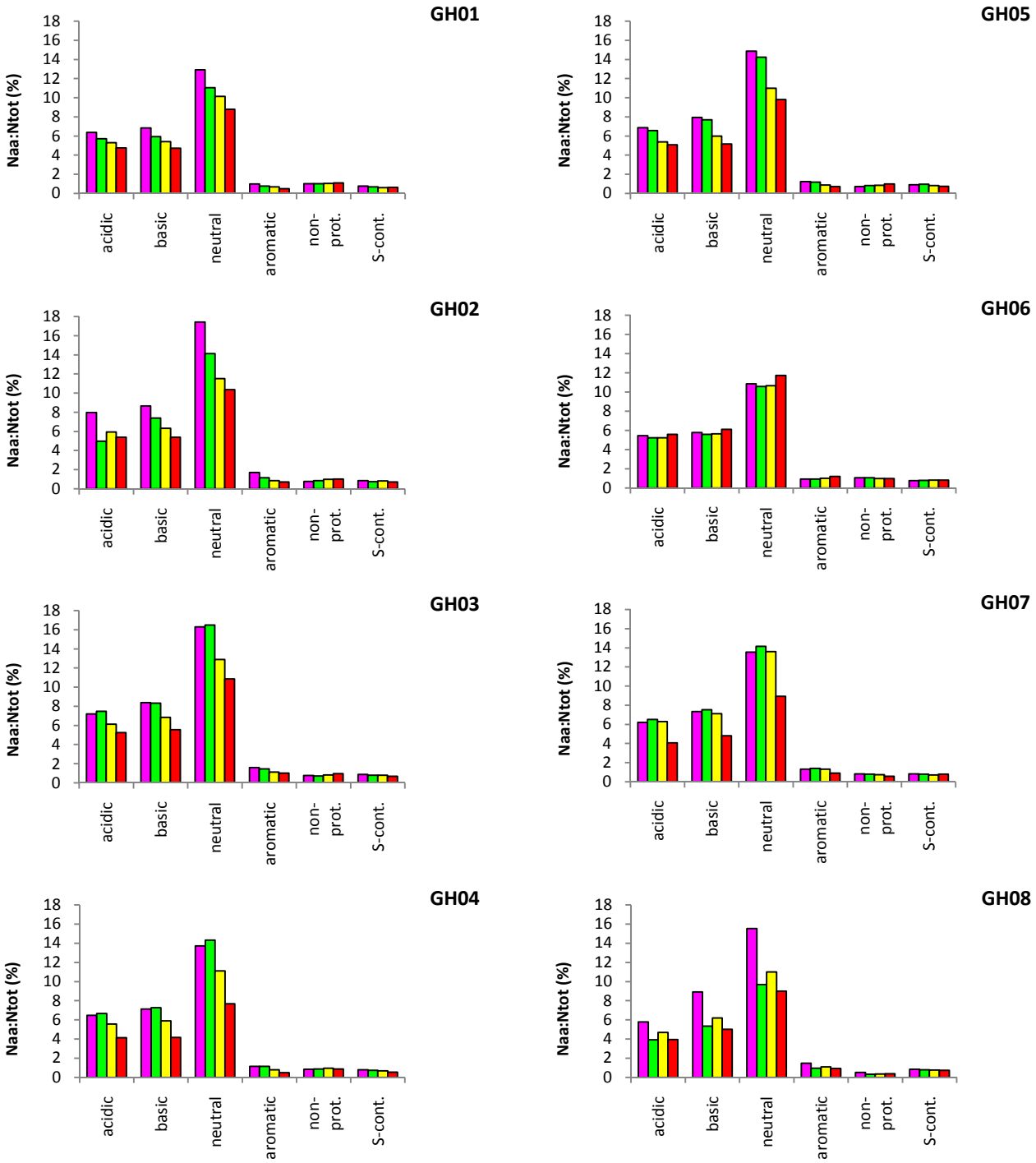


Figure 4.28: Down-core variation in contribution of each amino acid group to the pool of N in the rainy season. 0-5 cm, 5-10 cm, 10-15 cm and 30-35 cm.

The relative abundance of acidic amino acids did not vary significantly with depth ($p > 0.05$). It was significantly higher in the dry season and tended to be lower at the sites which were more affected by the inundation as compared to the drier and more saline sediments (table 4.8). On the contrary, the contribution of acidic amino acids to the pool of OC and TN was significantly different between depths and sites ($p < 0.001$). The C_{aa}:OC ratio was significantly higher in the rainy season ($p < 0.001$) while there was no significant difference in N_{aa}:TN ratio between the seasons ($p > 0.05$).

The relative abundance of basic amino acids did not vary significantly between depths and seasons ($p > 0.05$). Contrary to the acidic group, the mole % of basic amino acids was higher at the sites that were more affected by tidal water (table 4.8). The contribution of basic amino acids to the pool of OC and TN in the sediments significantly decreased with depth ($p < 0.001$). These ratios were higher in the rainy season but the significant difference was seen in the C_{aa}:OC ratio exclusively ($p < 0.001$).

The neutral amino acids relative abundance significantly decreased down-core (table 4.8) ($p < 0.001$). They tended to be more abundant at the tidal-affected-sites. Similar to the acidic and basic group, the C_{aa}:OC and N_{aa}:TN in the neutral amino acids also significantly decreased with depth ($p < 0.001$). These ratios were higher in the rainy season but the significant seasonal difference was found in C_{aa}:OC ratio exclusively ($p < 0.001$).

Table 4.8: Relative abundance (mole %) of the amino acid groups in the sediments at each site.

		acidic		basic		neutral		aromatic		non-protein		sulfur-containing	
Site	**Depth (cm)**	**dry**	**rainy**	**dry**	**rainy**	**dry**	**rainy**	**dry**	**rainy**	**dry**	**rainy**	**dry**	**rainy**
GH01	00-05	26.1	25.9	9.6	9.9	53.6	52.4	4.3	4.0	3.5	4.2	2.9	3.5
	05-10	26.4	26.6	9.7	10.0	52.6	51.3	3.9	3.7	4.1	4.8	3.4	3.7
	10-15	27.2	26.7	9.7	10.0	51.2	51.1	3.5	3.5	4.6	5.3	3.8	3.5
	30-35	28.0	26.9	9.9	10.0	48.7	49.7	2.6	2.9	6.2	6.3	4.5	4.2
GH02	00-05	26.8	25.1	9.1	9.4	54.5	54.8	4.8	5.4	2.5	2.5	2.4	2.9
	05-10	27.6	20.8	9.6	10.6	52.1	57.0	3.6	4.7	3.8	3.5	3.3	3.4
	10-15	27.6	26.4	10.0	10.1	50.4	51.1	3.1	3.8	4.9	4.4	4.1	4.2
	30-35	27.2	26.5	9.8	9.7	51.2	51.0	3.0	3.5	4.8	5.1	4.0	4.1
GH03	00-05	25.4	24.3	10.0	9.9	54.1	54.8	4.4	5.3	3.0	2.6	3.1	3.2
	05-10	26.0	24.9	10.3	9.8	53.0	55.1	4.2	4.9	3.3	2.4	3.2	2.9
	10-15	26.5	25.2	10.2	10.1	52.1	53.0	4.0	4.6	4.0	3.4	3.2	3.7
	30-35	26.7	25.2	10.0	9.8	51.5	52.0	4.0	4.9	4.2	4.6	3.6	3.6
GH04	00-05	25.4	25.2	10.1	9.9	53.8	53.6	4.2	4.5	3.3	3.3	3.2	3.4
	05-10	26.7	25.3	10.2	9.8	52.0	54.2	3.5	4.3	4.3	3.3	3.5	3.1
	10-15	27.6	26.1	9.9	10.1	51.2	52.0	3.3	3.6	4.4	4.5	3.6	3.6
	30-35	28.0	27.1	10.3	10.2	49.9	50.0	3.1	3.1	5.0	5.7	3.7	3.9
GH05	00-05	26.0	25.0	10.7	10.2	52.2	54.0	3.7	4.5	3.1	2.7	4.3	3.7
	05-10	26.4	24.6	10.4	10.4	53.1	53.3	3.8	4.4	3.0	3.2	3.3	4.1
	10-15	27.1	25.4	10.5	10.2	50.8	51.7	3.4	4.1	4.0	4.1	4.2	4.4
	30-35	22.9	26.3	10.9	9.8	53.1	50.6	3.3	3.7	5.6	5.2	4.2	4.5
GH06	00-05	26.1	25.7	10.0	10.1	52.6	50.9	4.4	4.2	3.7	5.0	3.2	4.1
	05-10	25.5	25.3	10.4	10.0	53.0	50.8	4.6	4.4	3.4	5.2	3.0	4.3
	10-15	25.9	25.3	10.3	10.0	52.8	51.0	4.7	4.6	3.1	4.8	3.2	4.3
	30-35	26.4	24.7	10.4	9.9	52.1	51.9	4.6	5.3	3.7	4.3	2.9	3.9
GH07	00-05	25.4	24.4	10.5	10.4	53.7	53.2	4.9	5.3	3.0	3.2	2.6	3.5
	05-10	25.2	24.6	10.4	10.3	53.8	53.4	4.5	5.3	3.0	3.1	3.0	3.3
	10-15	25.2	24.9	10.3	10.1	53.7	53.7	5.0	5.3	3.1	3.0	2.7	3.1
	30-35	24.8	23.7	10.6	10.2	51.6	52.1	4.9	5.3	4.1	3.4	3.9	5.3
GH08	00-05	24.2	21.7	10.0	11.2	52.6	56.1	4.1	5.2	2.1	1.9	7.0	3.9
	05-10	23.2	22.2	10.3	10.7	53.3	54.8	4.4	5.4	2.1	1.9	6.7	5.0
	10-15	22.6	23.3	10.6	10.8	54.4	54.6	5.1	5.4	1.8	1.7	5.6	4.2
	30-35	24.0	23.4	10.0	10.6	55.5	53.4	5.4	5.5	2.3	2.2	2.9	4.9

The mole % of sulfur-containing and non-proteinaceous amino acids did not vary significantly between the dry and rainy season ($p > 0.05$). Their relative abundance, however, significantly increased down-core ($p < 0.001$ for the non-protein amino acids and $p < 0.05$ for the sulfur-containing amino acids). The relative abundance of non-protein amino acids was highest at the dry and saline sites (table 4.8) ($p < 0.001$) while the relative abundance of sulfur-containing amino acids tended to increase with the sediment pH (table 4.8).

The contribution of sulfur-containing amino acids to the pool of OC and TN also decreased with depth ($p < 0.05$ for C_{aa}:OC and $p < 0.001$ for N_{aa}:TN ratio). These ratios were significantly higher in the rainy season ($p < 0.001$). The significant difference between depths in the contribution of non-protein amino acids to the total OC and TN was found in the C_{aa}:OC ratio only ($p < 0.001$). Due to their relative abundance, the C_{aa}:OC and $N_{aa:}$TN ratio in the non-protein amino acids were highest at GH01 while these ratios in the sulfur-containing amino acids were highest at the carbonate site (GH05) (table 4.8).

The composition pattern of amino acids in the dry and rainy season is presented in figure 4.29 and 4.30, respectively. Aspartic acid (Asp), glutamic acid (Glu), glycine (Gly) and alanine (Ala) were the most abundant amino acids in the sediments in the sampling year, while taurine (Tau) and methionine (Met) were found as traces only. This finding is consistent through the depths and landscapes, regardless of the seasonal periods. The average contribution of Gly to the THAAs in the sediment was 14.4 and 13.6 mole % in the dry and rainy season, respectively. The total acidic amino acids, calculated by the sum of Glu and Asp, accounted for 13 and 12.5 mole % in the dry and rainy season, respectively. Asp was more abundant as compared to Glu, as the Asp:Glu ratio was *ca.* 1.2 in both sampling seasons. Ala contributed 10.3 and 10.03 % to the total mole concentration of the hydrolysable amino acids in the dry and rainy season, respectively.

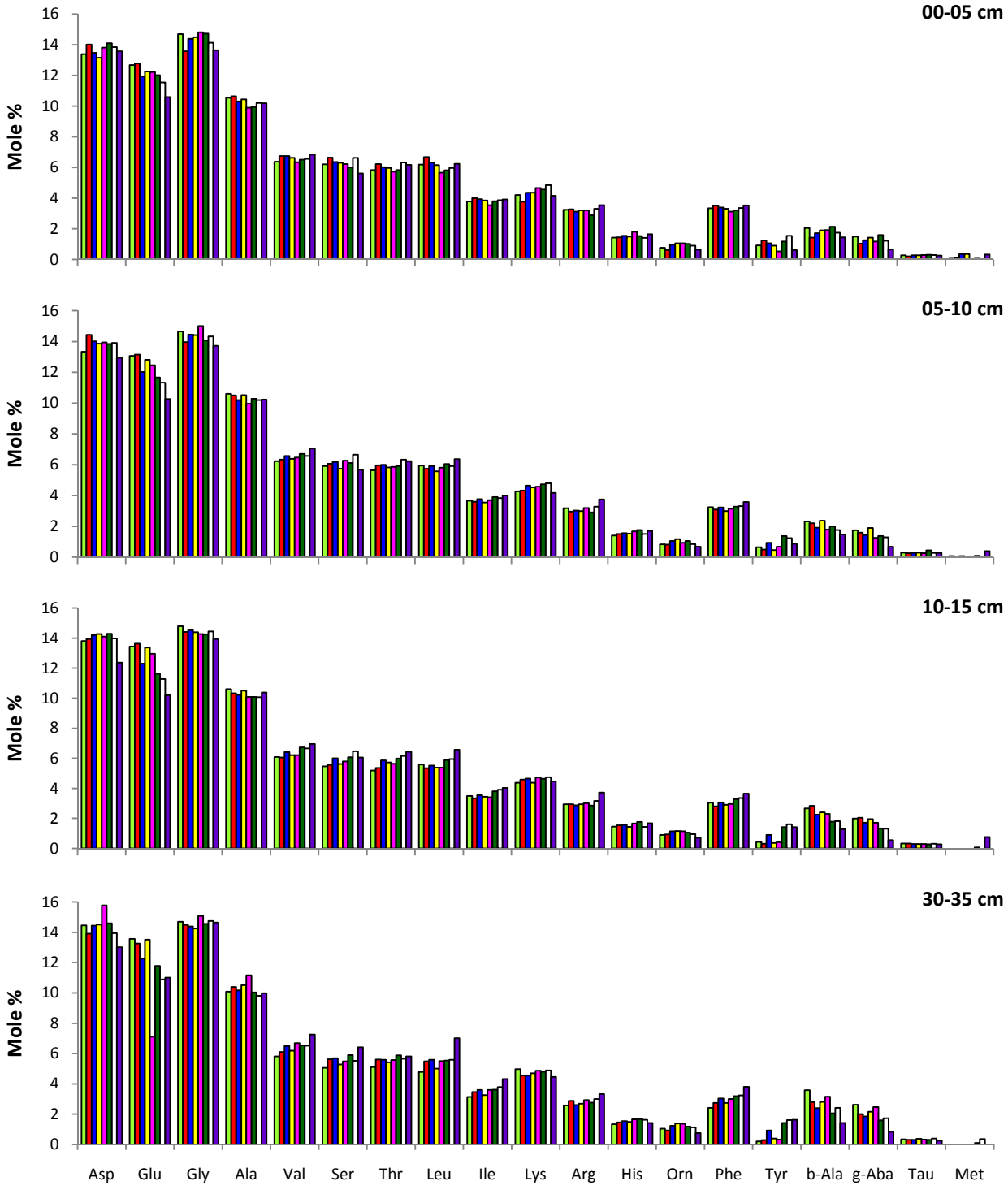


Figure 4.29: Composition pattern of amino acids in the sediments in the dry season. GH01, GH02, GH03, GH04, GH05, GH06, GH07, GH08

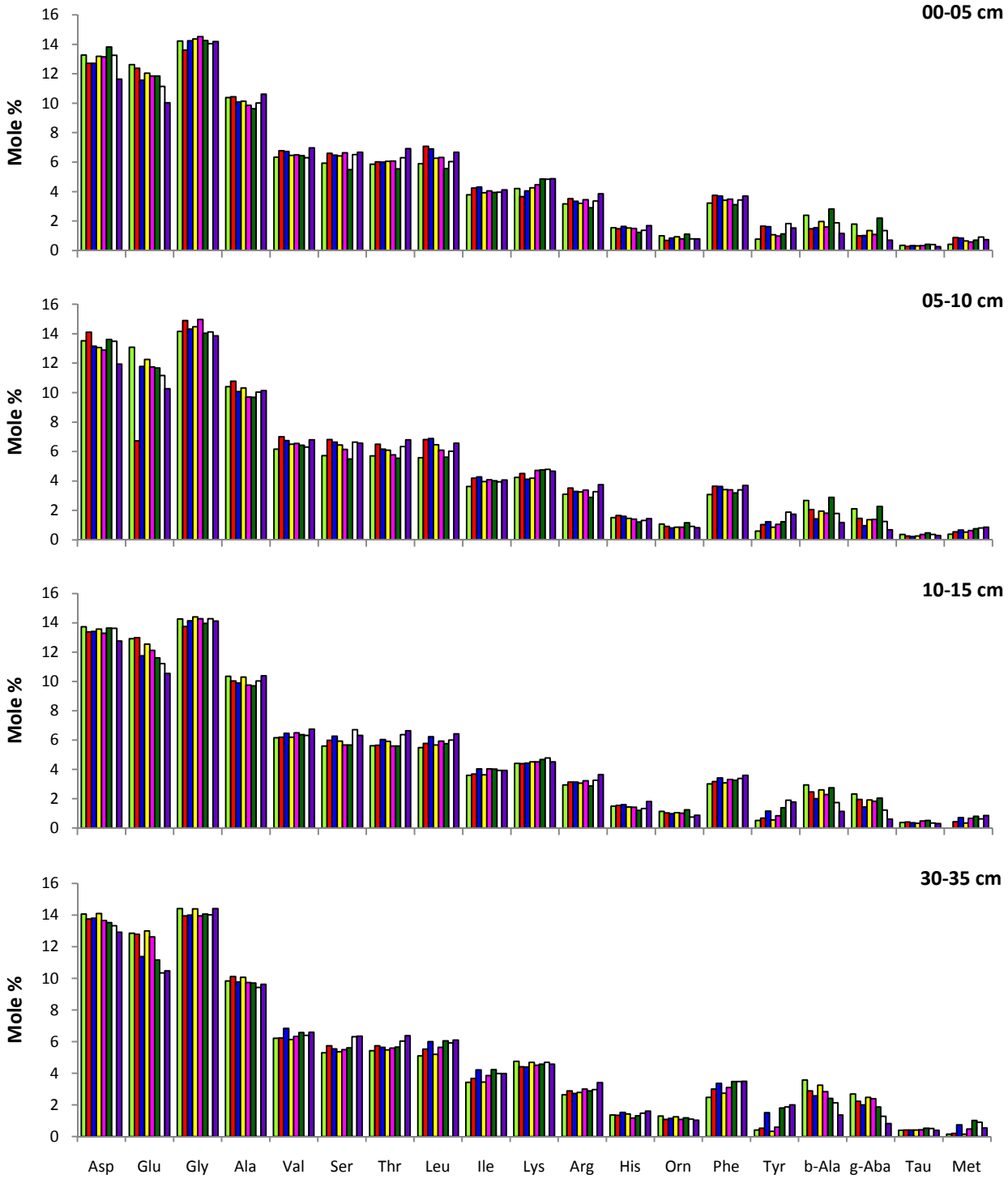


Figure 4.30: Composition pattern of amino acids in the sediments in the rainy season. GH01, GH02, GH03, GH04, GH05, GH06, GH07, GH08

The individual amino acids showed the varied tendency of downward variation at each sampling site. The downward variation of Gly mole % at the sampling sites is presented in the figure 4.31. It increased from 0-15 cm at GH01, GH02 and varied negligibly with depth at GH04 in the dry season. The down-core increases were also found at GH3, GH7 and GH8 in the dry season while the down-core decrease was seen at GH06 in both seasons. No trend was seen at GH05 as the Gly mole fraction increased at 5-10 and 30-35 cm.

The mole % of Ser was higher than Thr in both sampling seasons ($p > 0.05$), with an exception found at GH08 in the both seasons (figure 4.32 and 4.33). The mole % of these two neutral amino acids tended to decrease with depth at most of the sampling sites, but increased down-core at GH08 in the dry season. In the rainy season, the mole % of Thr and Ser at GH02 increase at 5-10 cm before falling to lower values at 10-15 cm. The downward variations of Ile and Leu were similar to the variations of Ser and Thr (figure 4. 34 and 4.35).

Val and Ala decreased with depth (figure 4.36 and 4.37) but the variation range was narrow, from 5.8 to 7.3 mole % in the sampling year for Val, and from 9.4 to 11.2 mole % for Ala. The downward variations of Ala were similar in the dry and rainy season. However, in the rainy season, sudden increases at 5-10 cm in Ala and Val mole % were seen at GH02.

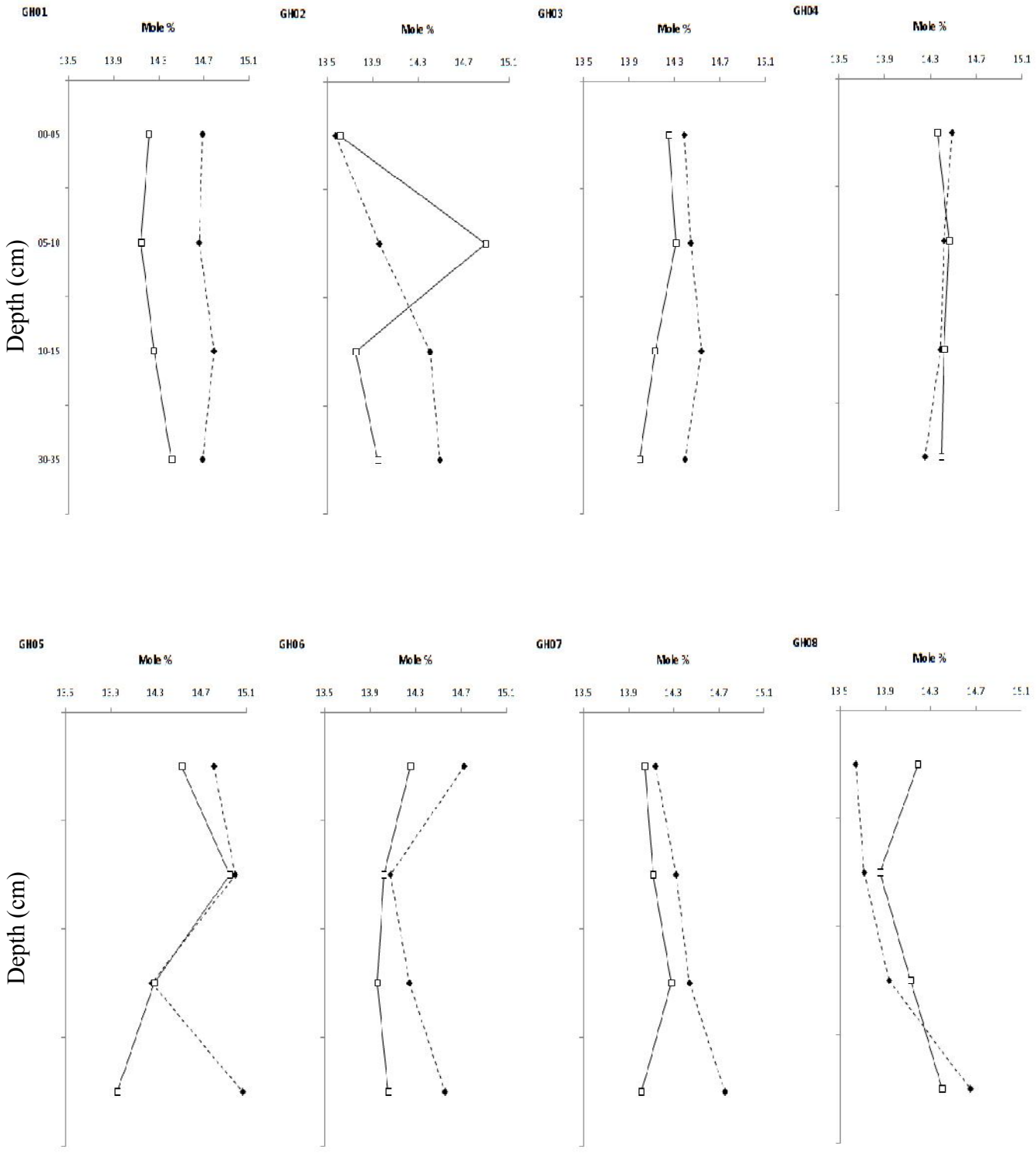


Figure 4.31: The downward variation of neutral amino acids (Gly) at each sampling site in 2 seasons. ◆ dry season; □ rainy season .

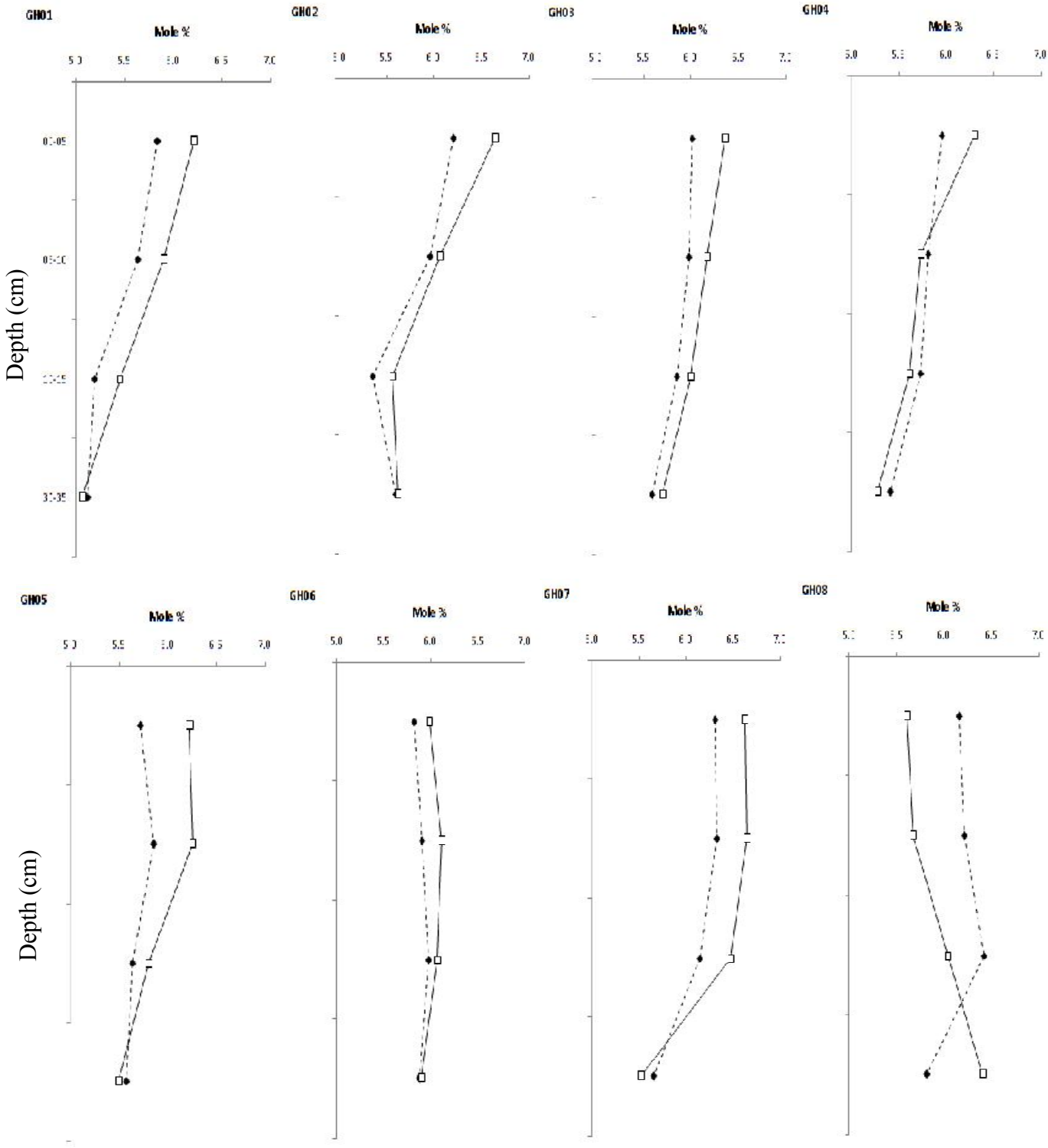


Figure 4.32: The downward variation of neutral amino acids (Thr and Ser) at each sampling site in the dry seasons. ◆Thr; □Ser .

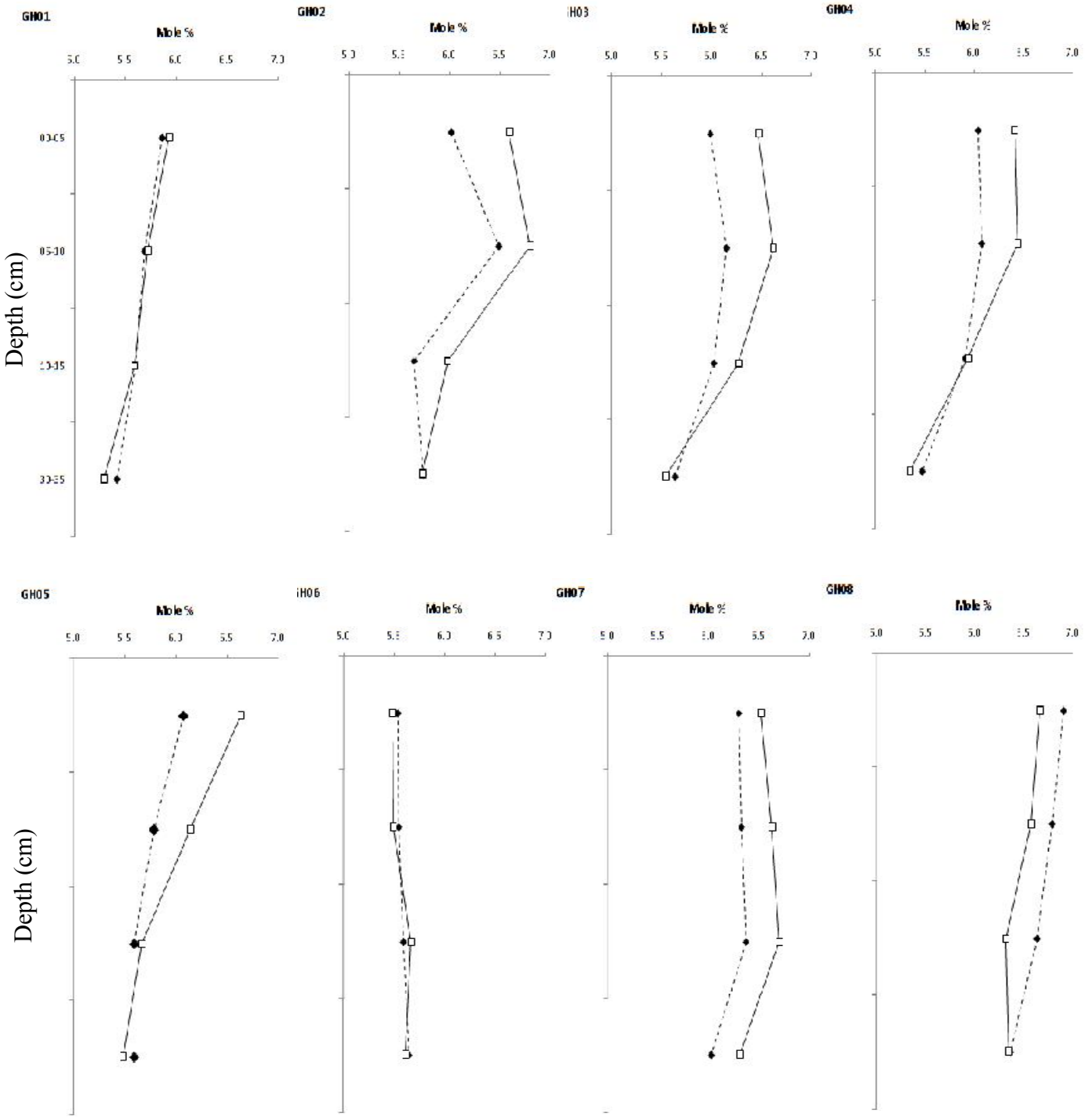


Figure 4.33: The downward variation of neutral amino acids (Thr and Ser) at each sampling site in the rainy seasons. ◆Thr; □ Ser .

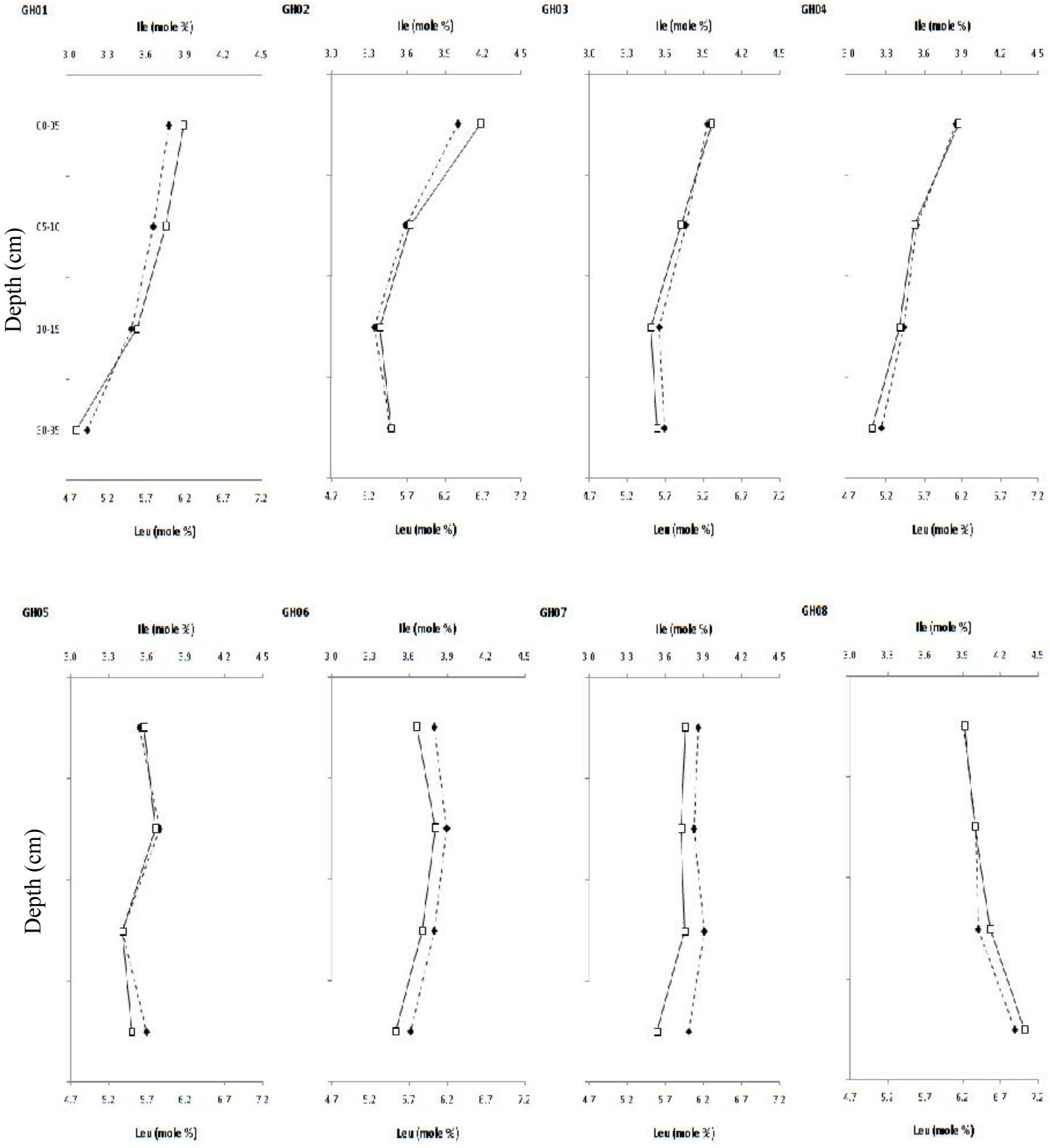


Figure 4.34: The downward variation of neutral amino acids (Ile and Leu) at each sampling site in the dry seasons. ◆Ile; □ Leu .

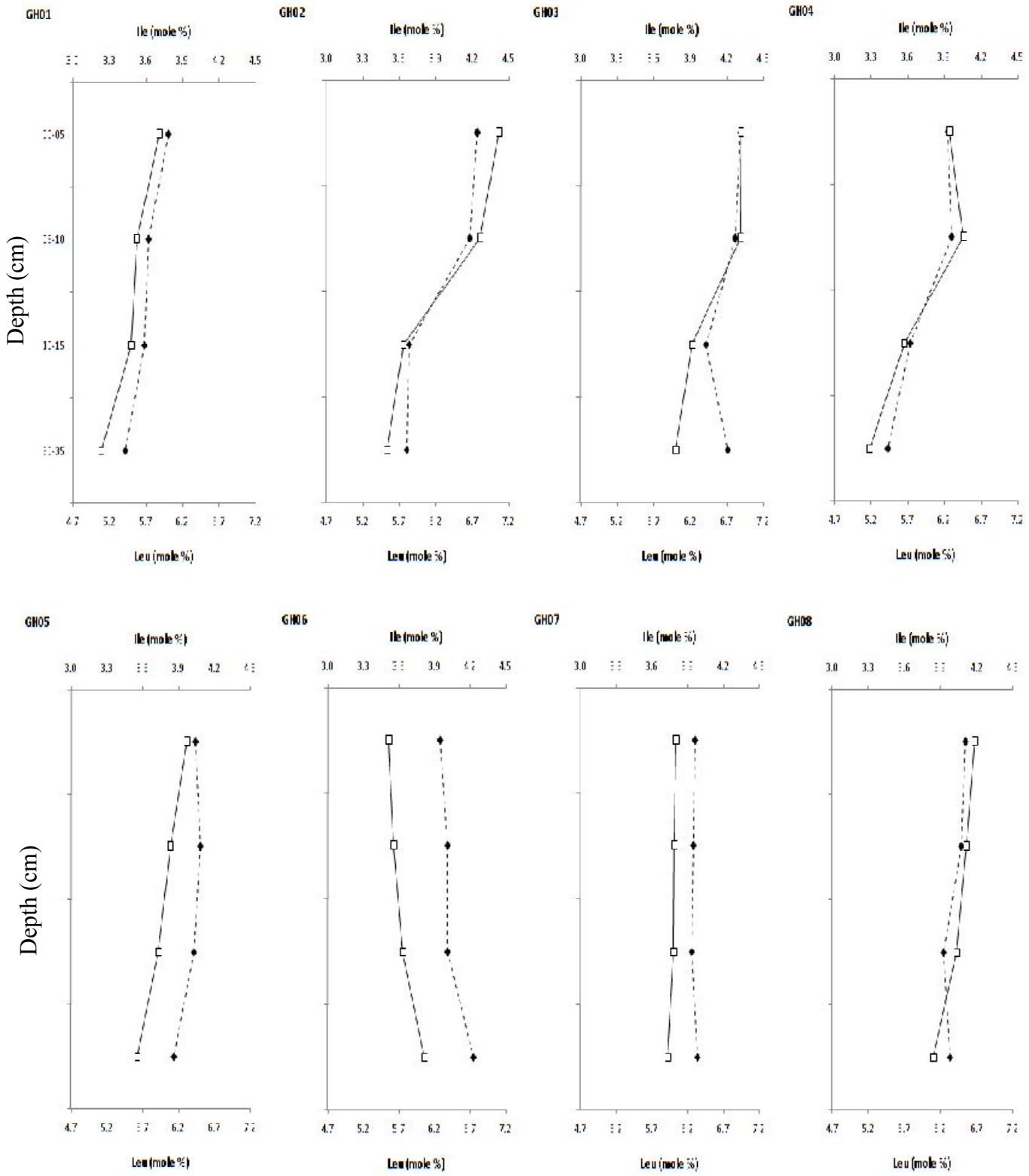


Figure 4.35: The downward variation of neutral amino acids (Ile and Leu) at each sampling site in the rainy seasons. ◆Ile; □Leu .

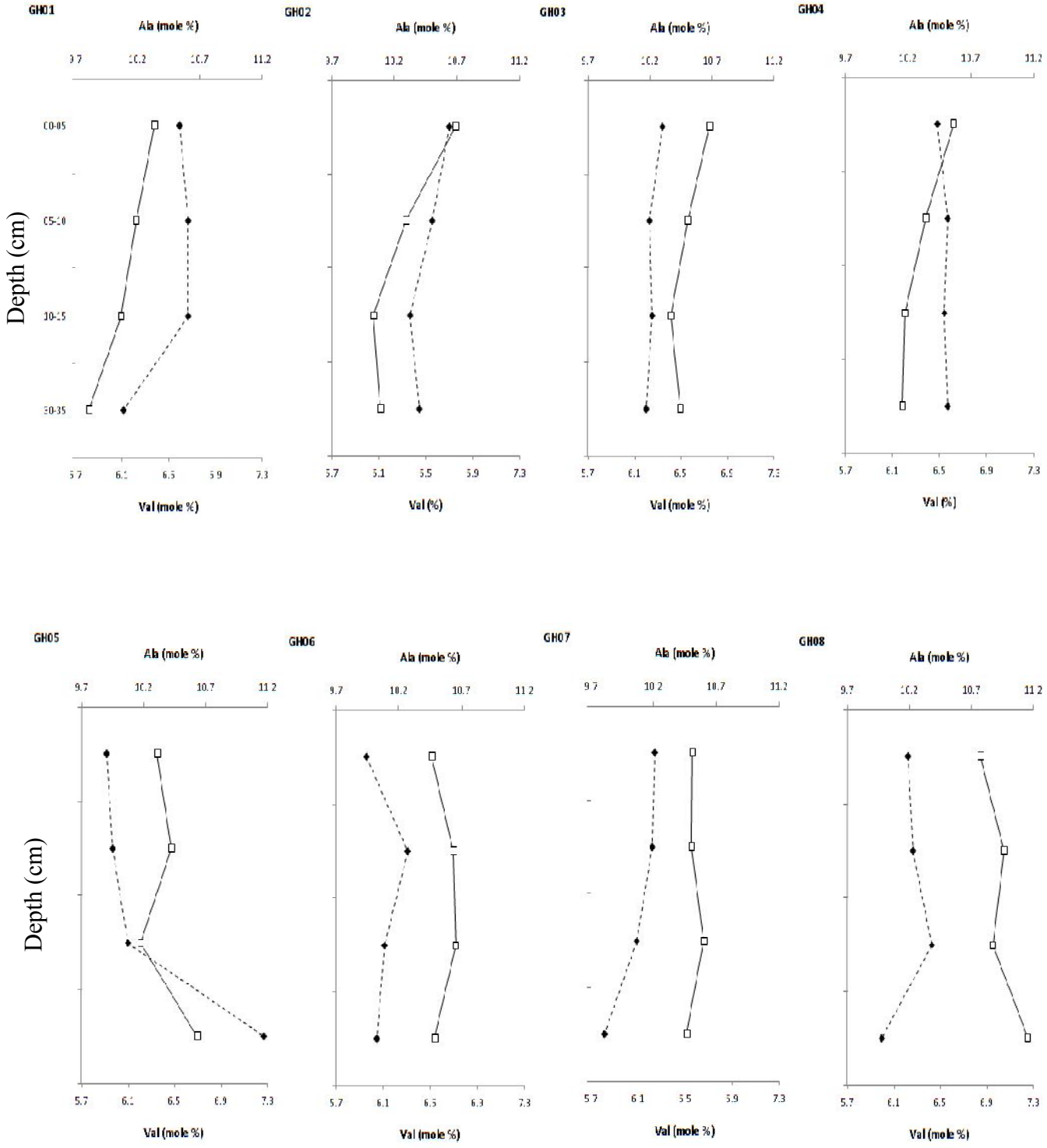


Figure 4.36: The downward variation of neutral amino acids (Ala and Val) at each sampling site in the dry seasons. ◆Ala; □ Val .

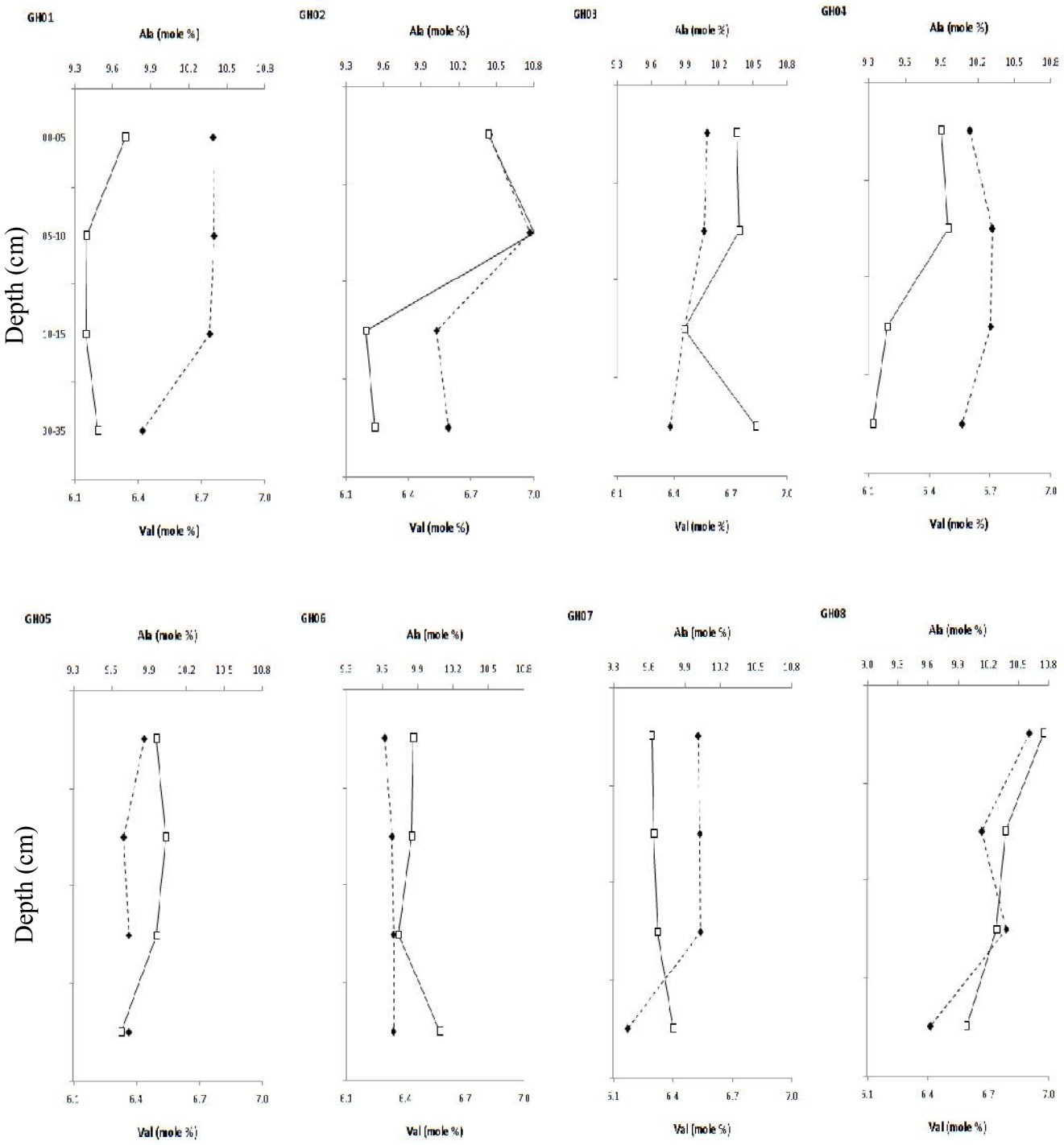


Figure 4.37: The downward variation of neutral amino acids (Ala and Val) at each sampling site in the rainy seasons. ◆ Ala; □ Val.

There were no significant differences in Asp and Glu concentration found between depths in the sampling year ($p > 0.05$). In general, Asp and Glu mole % increased down-core negligibly (figure 4.39 and 4.40), indicating their production in the deeper sediments. At the interior sites, the mole % of Asp and Glu increased down-core but the downward variations were negligible at the exterior sites (figure 4.39 and 4.40). Within 0-15 cm, the Asp:Glu ratio was *ca.* 1.3 and increased towards the tidal affected sites in both seasons (figure 4.38). There was a sudden high of Asp:Glu ratio at GH05 in the dry season, corresponding with the high pH value at 30-35 cm (figure 4.38).

At the *Avicennia* fringe (GH06), the mole % of β-Ala and γ-Aba decreased down-core in both of the sampling times (figure 4.48 and 4.49), suggesting a loss of these non-protein amino acids in the sediment beneath the surface. The down-core increase in β-Ala and γ-Aba were significant only in the dry season ($p < 0.05$). The Asp:β-Ala and Glu:γ-Aba ratios were significantly different from site to site in both of the sampling seasons ($p < 0.01$). The Asp:β-Ala in the dry and rainy season was similar to each other with the values is of *ca*. 4. On average, the Glu:γ-Aba ratios, on the other hand, varied from 2.9 in the dry season to 4.6 in the rainy season. Seasonal changes in sediment conditions did not influence the values of these ratios, as well as the mole % of the non-protein amino acids.

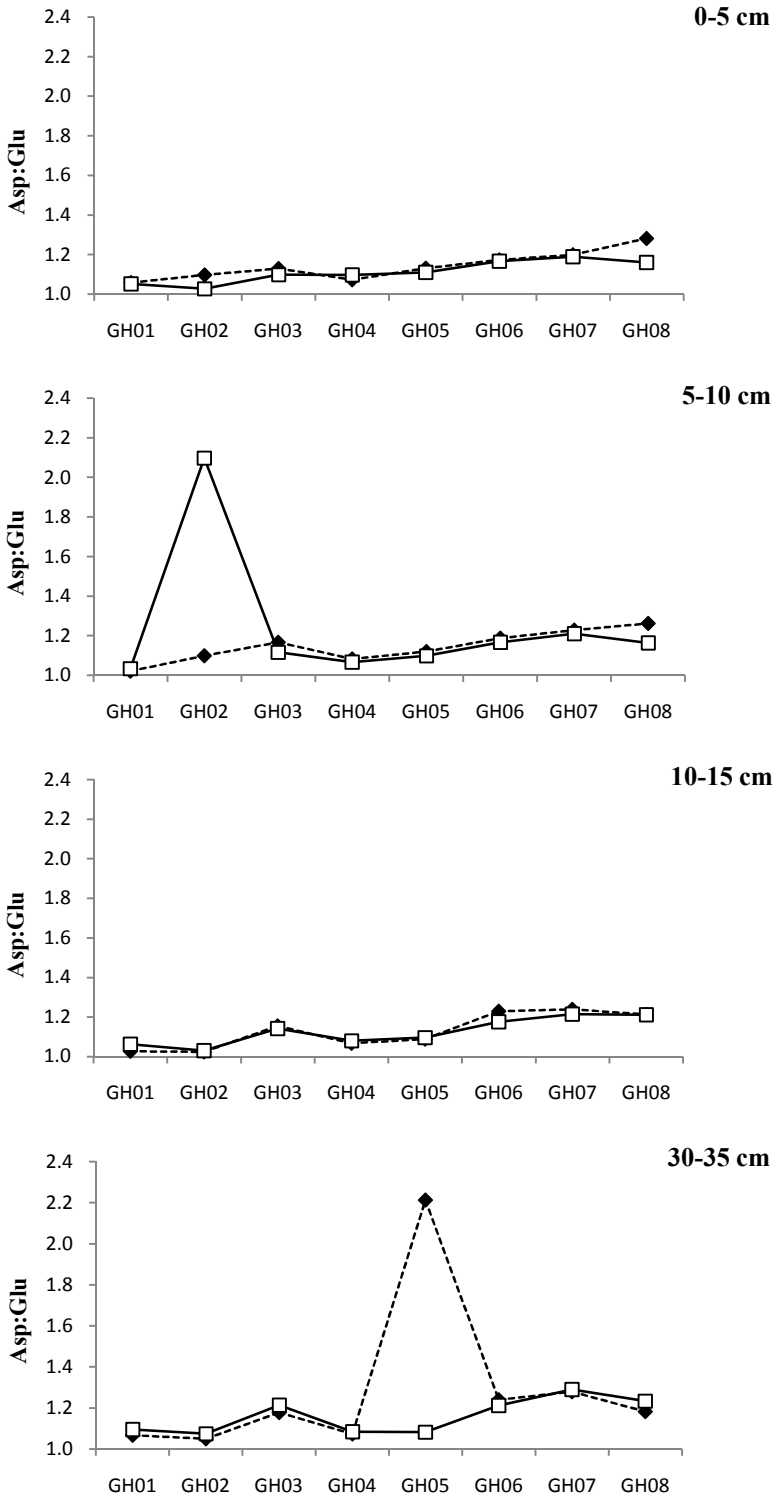


Figure 4.38: Variation of Asp:Glu ratio along the transect in the dry and rainy season. ◆Dry season; □ rainy season.

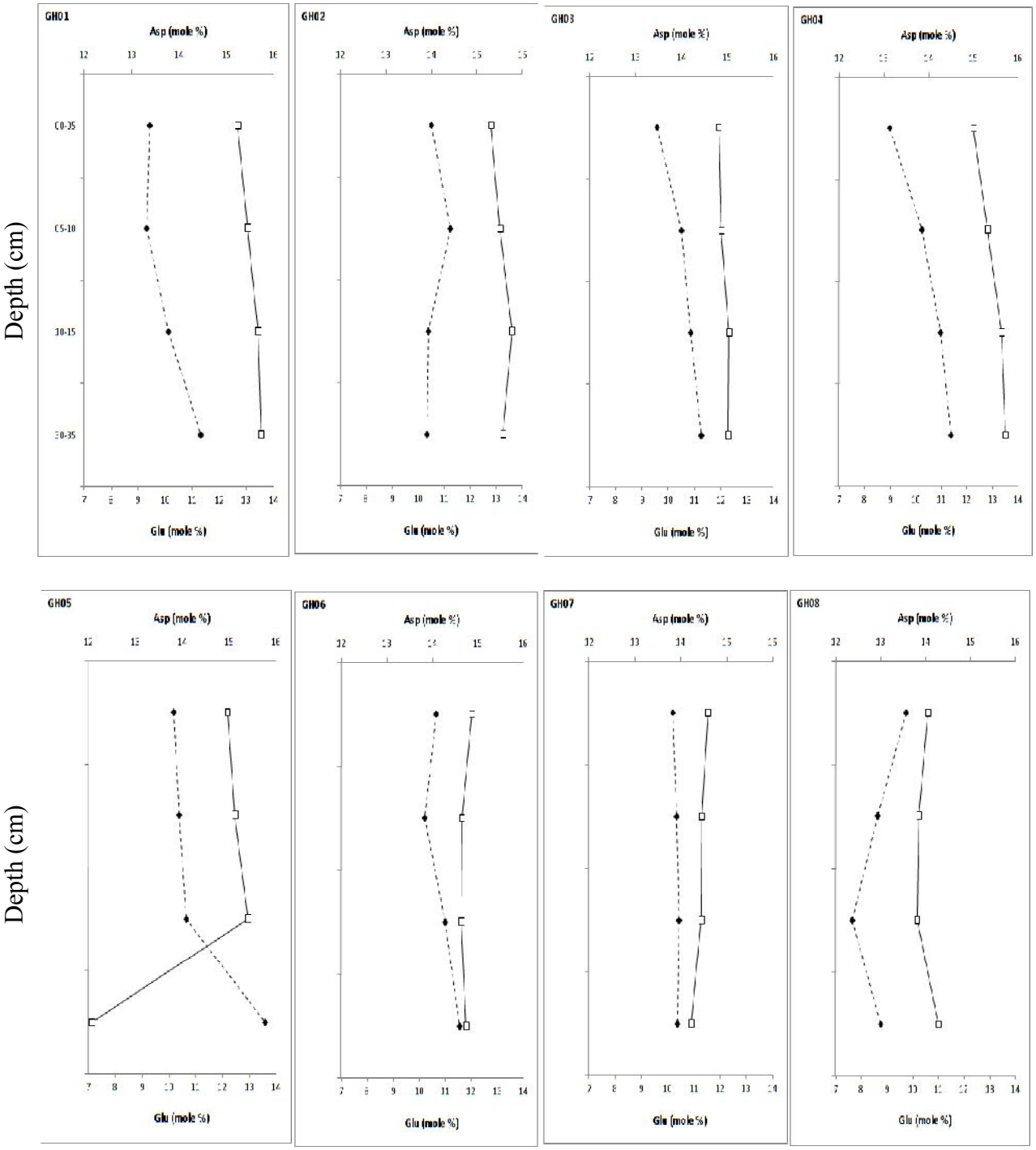


Figure 4.39: The downward variation of acidic amino acids (Asp and Glu) at each sampling site in the dry season. ◆ Asp; □ Glu.

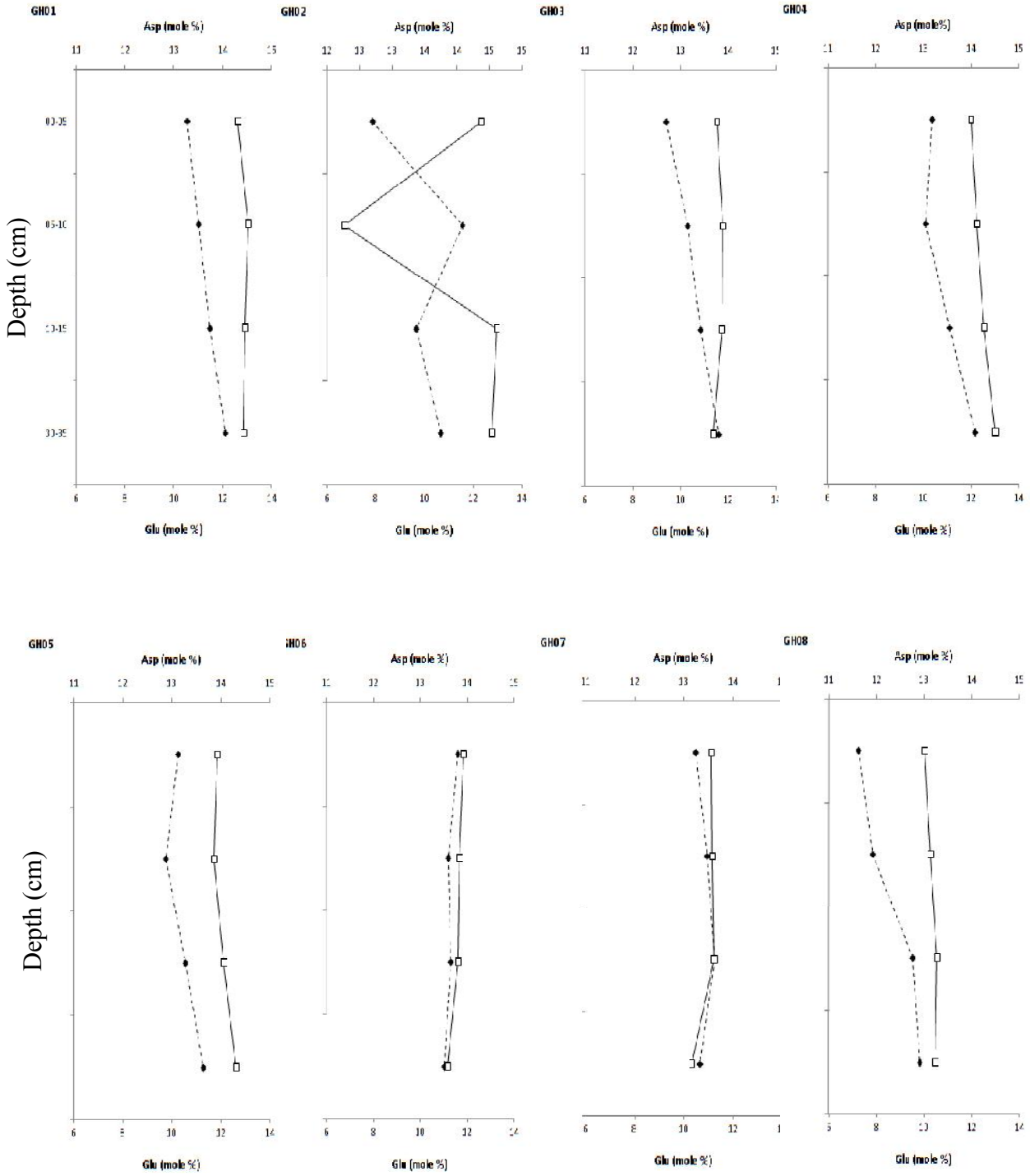


Figure 4.40: The downward variation of acidic amino acids (Asp and Glu) at each sampling site in the rainy season. ◆Asp; □ Glu.

In general, the depth variation of His was very negligible at most of the samling sites, except for an increase at 5-10 cm at GH02 in both seasons (figure 4.41). Another exception was seen at 5-10 cm at GH06 in the dry season. Arg decreased with depth at most of the sampling sites. However, a slight increase from 0-5 (3.55 mole %) to 5-10 cm 3.74 mole %) at GH08 was found in the dry season. The mole % of Lys increased down-core at GH01, GH02, GH03 and GH04 in both seasons but tended to decreased downcore at the other sites (figure 4.42 and 4.43).

The mole % of Orn consistently increased with depth, inversely proportional to the down-core variation of Arg (figure 4.44). The Arg:Orn ratio consistently decreased with depth in the sediments (figure 4.45), but the significant difference was found in the rainy season only ($p < 0.01$). The Arg:Orn ratio varied between 1.9 and 5.5 in the dry season and from 2.1 to 5.1 in the rainy season. There was no seasonal difference in the Arg:Orn ratio, similar to the Asp:β-Ala and Glu:γ-Aba ratios ($p > 0.05$).

The mole fraction of Tyr and Phe decreased down-core at most of the sampling sites in the dry and rainy season (figure 4.46 and 4.47). The mole % of the non-protein amino acids (β-ala and γ-aba) increased with depth at all of the sampling sites. However, the variation is more apparent in the interior sites compared to the exterior sites (figure 4.48 and 4.49). The mole % of β-Ala and γ-Aba increased with depth at all sampling sites from GH01 to GH05 but it tended to increase down-core at GH06, GH07 and GH08 in both seasons (figure 4.48 and 4.49).

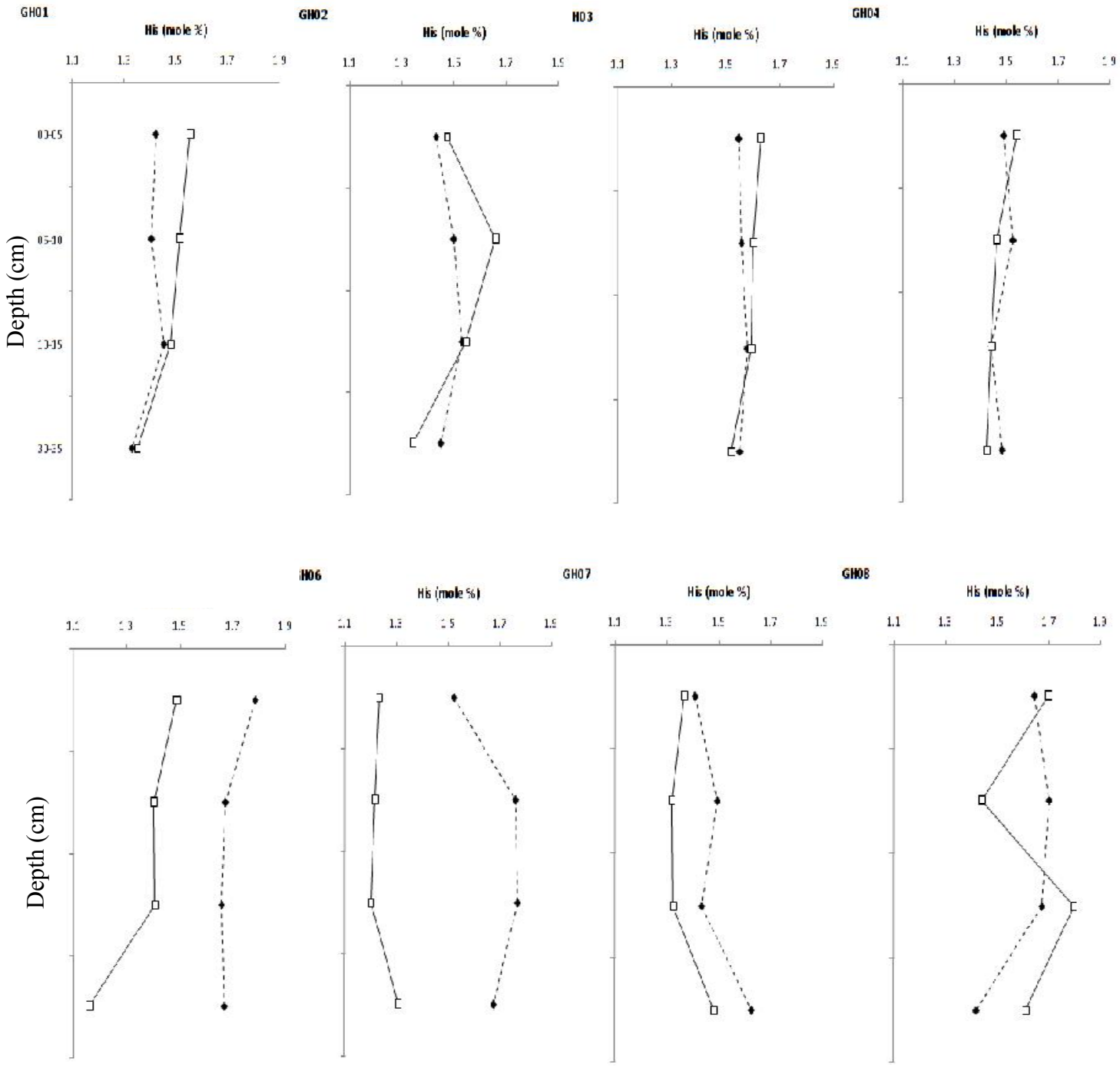


Figure 4.41: The downward variation of basic amino acids (His) at each sampling site in both seasons. ◆ dry season; □ rainy season.

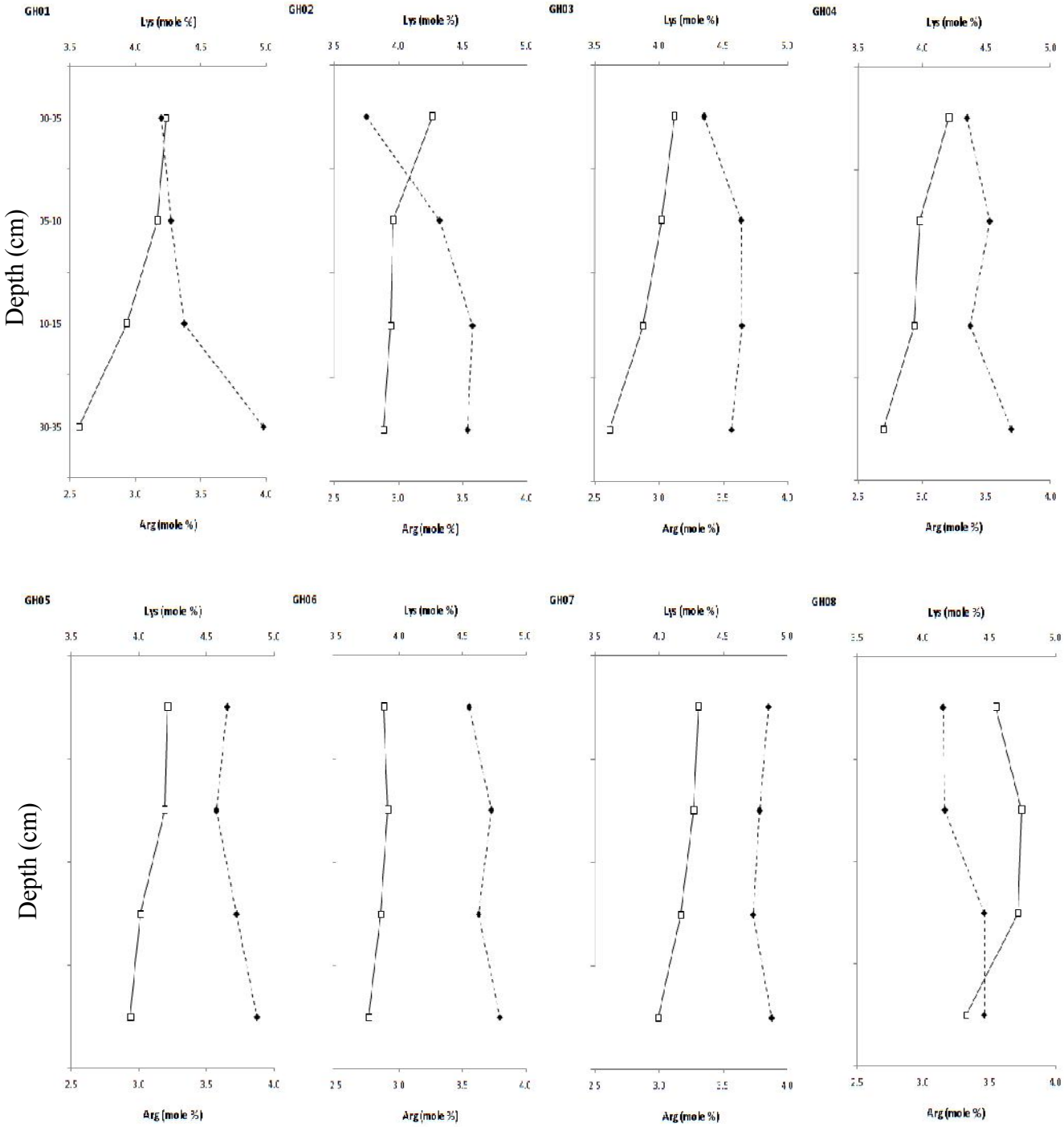


Figure 4.42: The downward variation of basic amino acids (Lys and Arg) at each sampling site in the dry season. ◆ Lys; □ Arg.

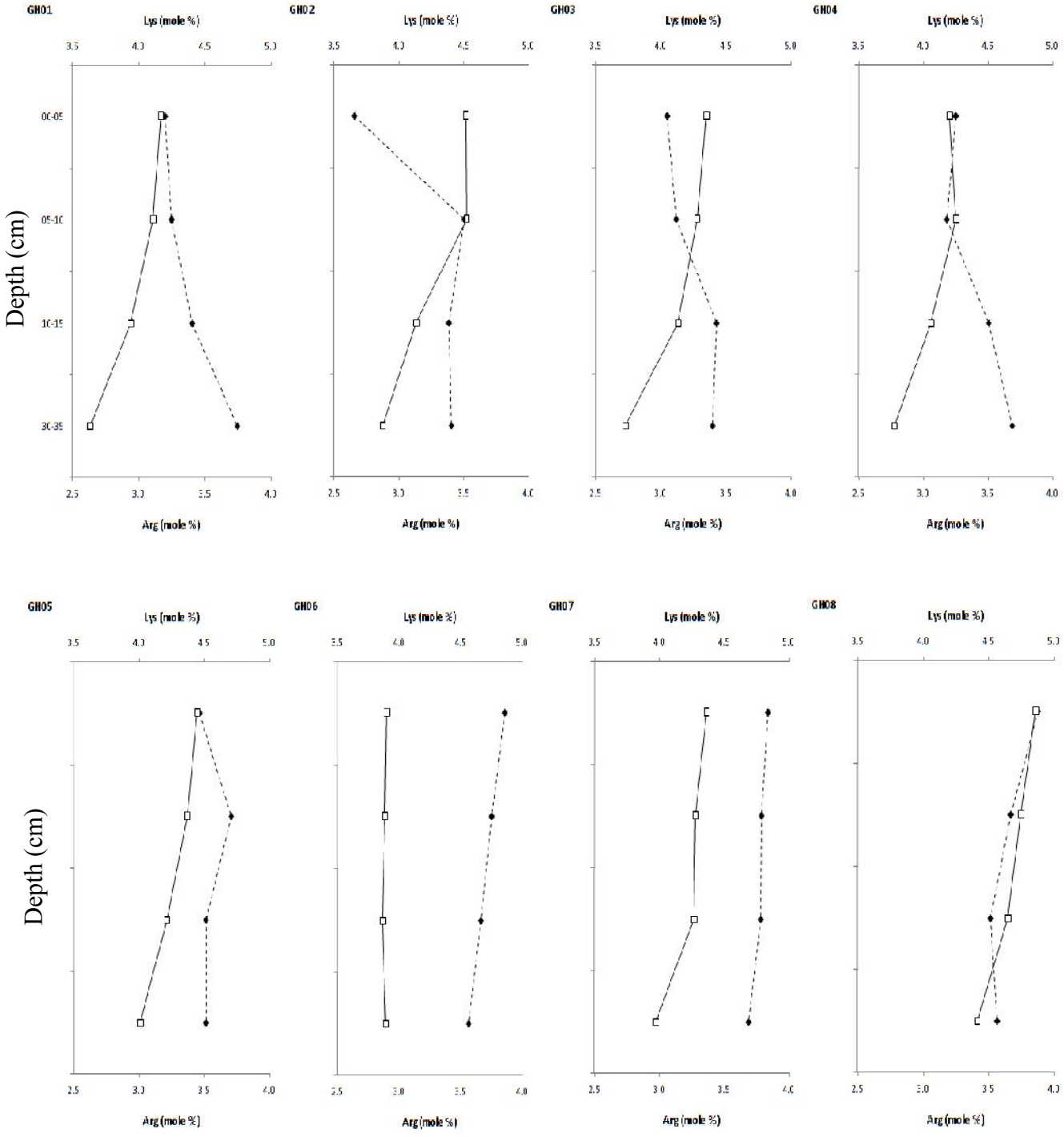


Figure 4.43: The downward variation of basic amino acids (Lys and Arg) at each sampling site in the rainy season. ◆Lys; □ Arg.

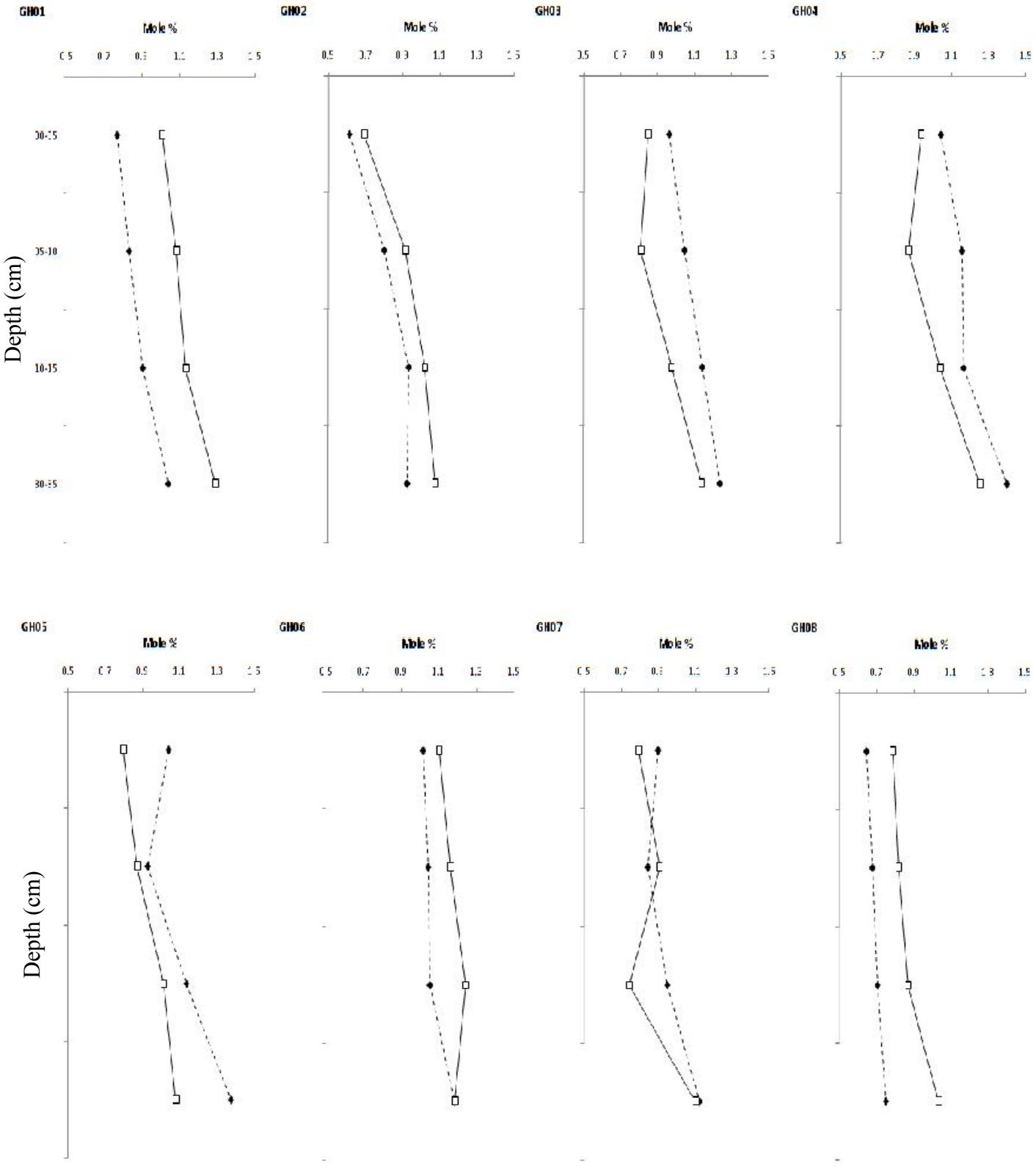


Figure 4.44: The downward variation of basic amino acids (Orn) at each sampling site in both seasons. ◆ Dry season; □ rainy season.

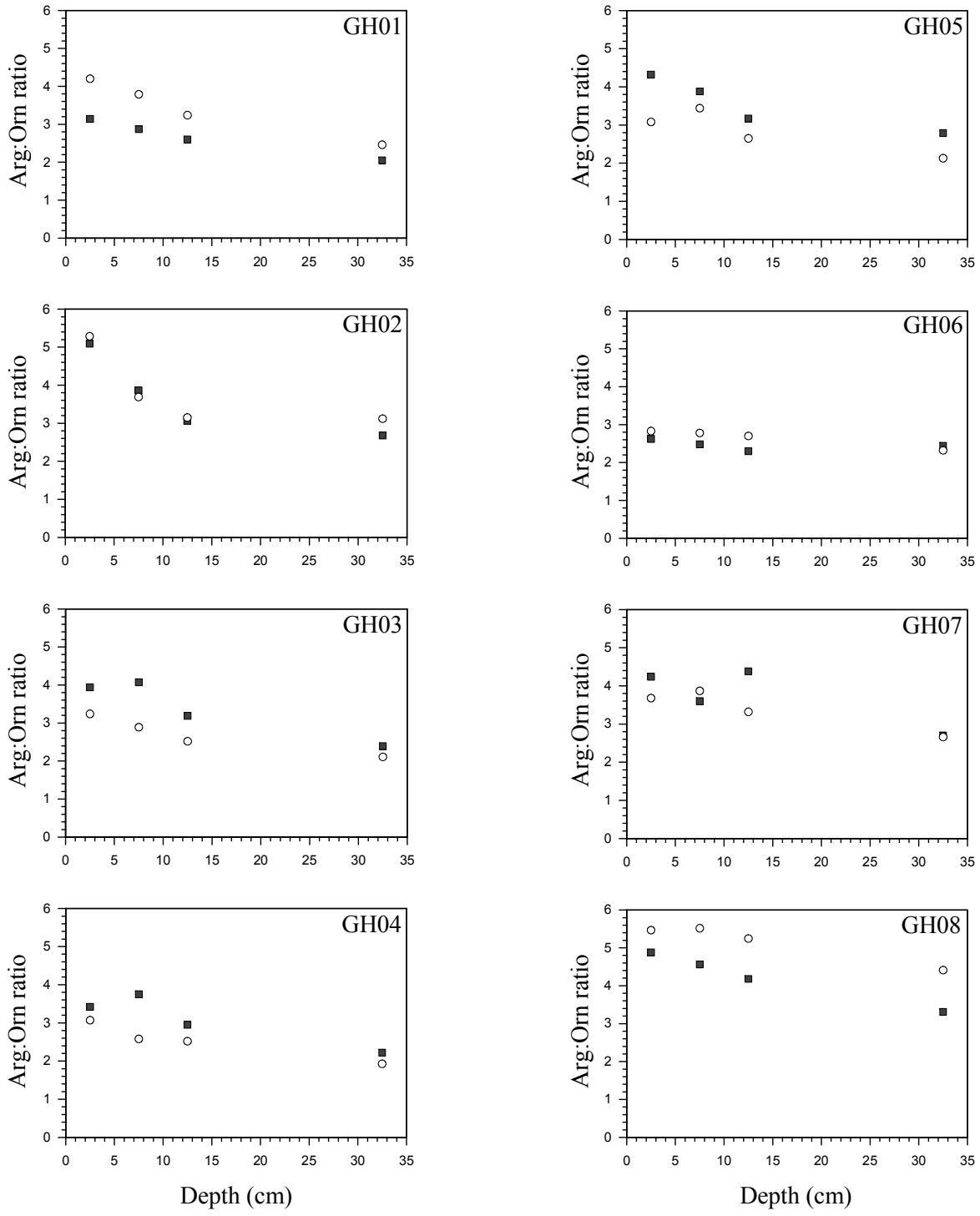


Figure 4.45: Down-core variation of Arg:Orn ratio in the sediments at each sampling site. ◯ Dry season, ■ rainy season.

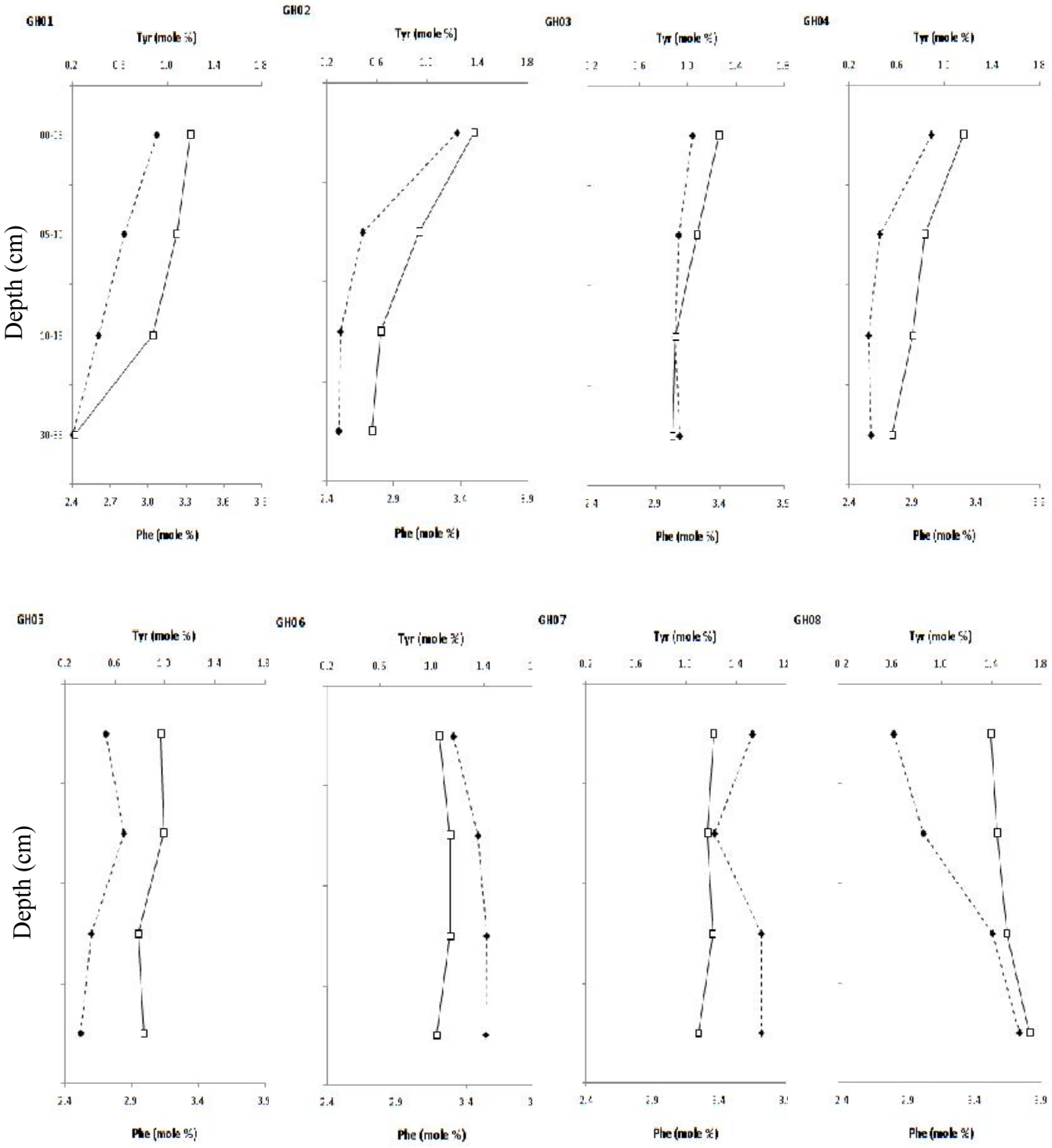


Figure 4.46: The downward variation of aromatic amino acids (Tyr and Phe) at each sampling site in the dry seasons. ◆ Tyr; □ Phe.

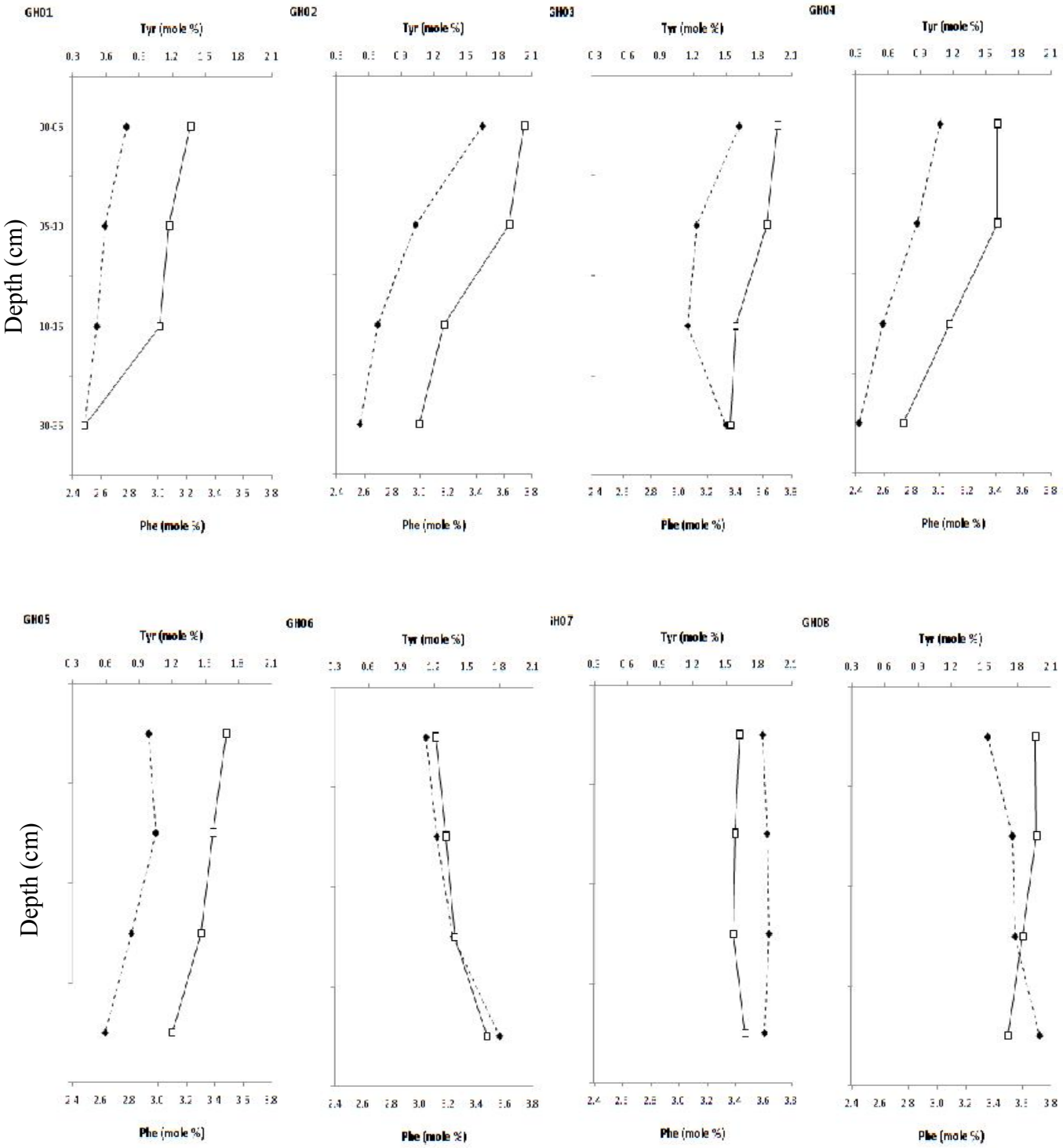


Figure 4.47: The downward variation of aromatic amino acids (Tyr and Phe) at each sampling site in the rainy seasons. ◆Tyr; □ Phe.

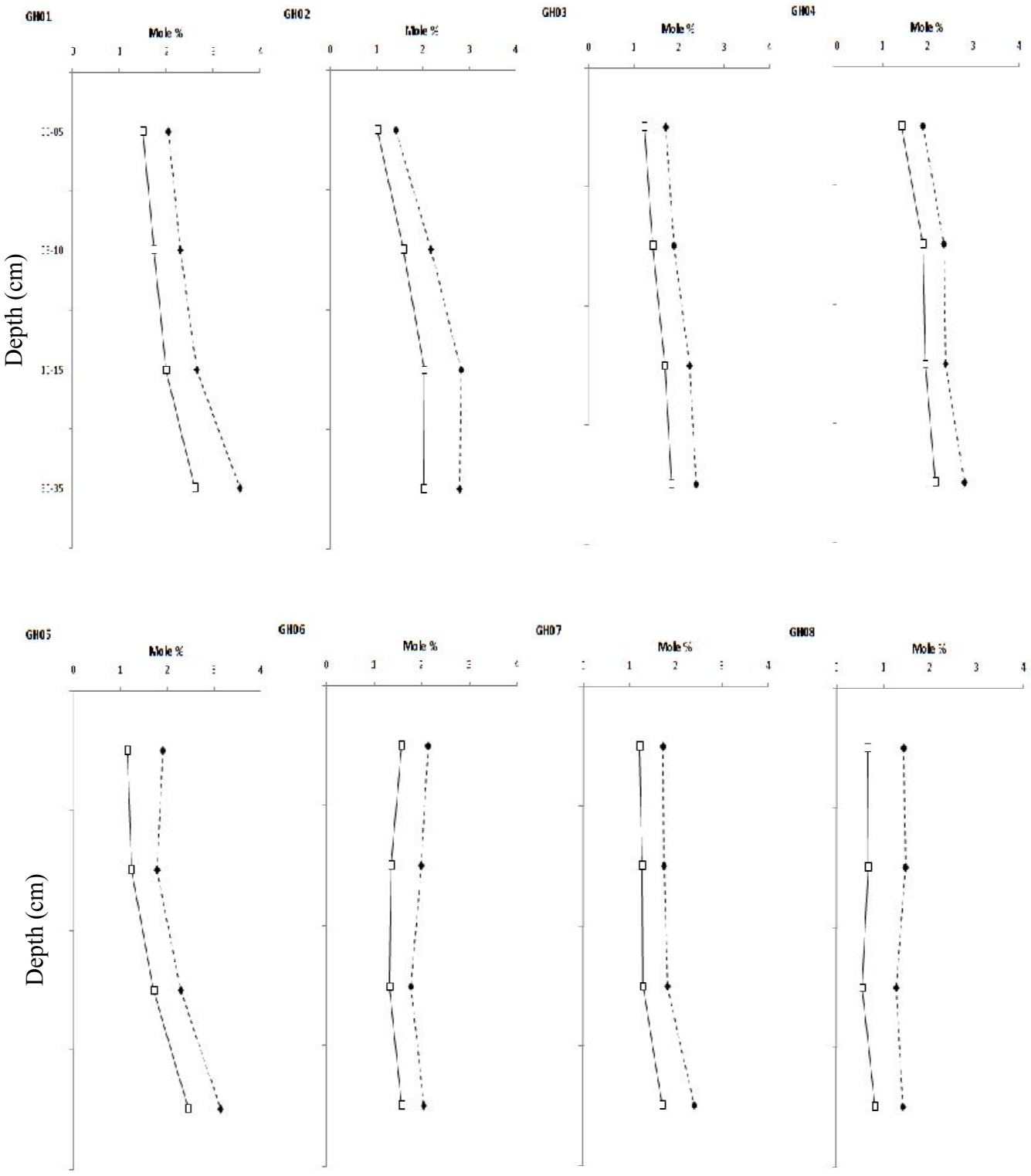


Figure 4.48: The downward variation of non-proteinaceous amino acids (β-Ala and γ-Aba) at each sampling site in the dry seasons. ◆ β-Ala; □ γ-Aba .

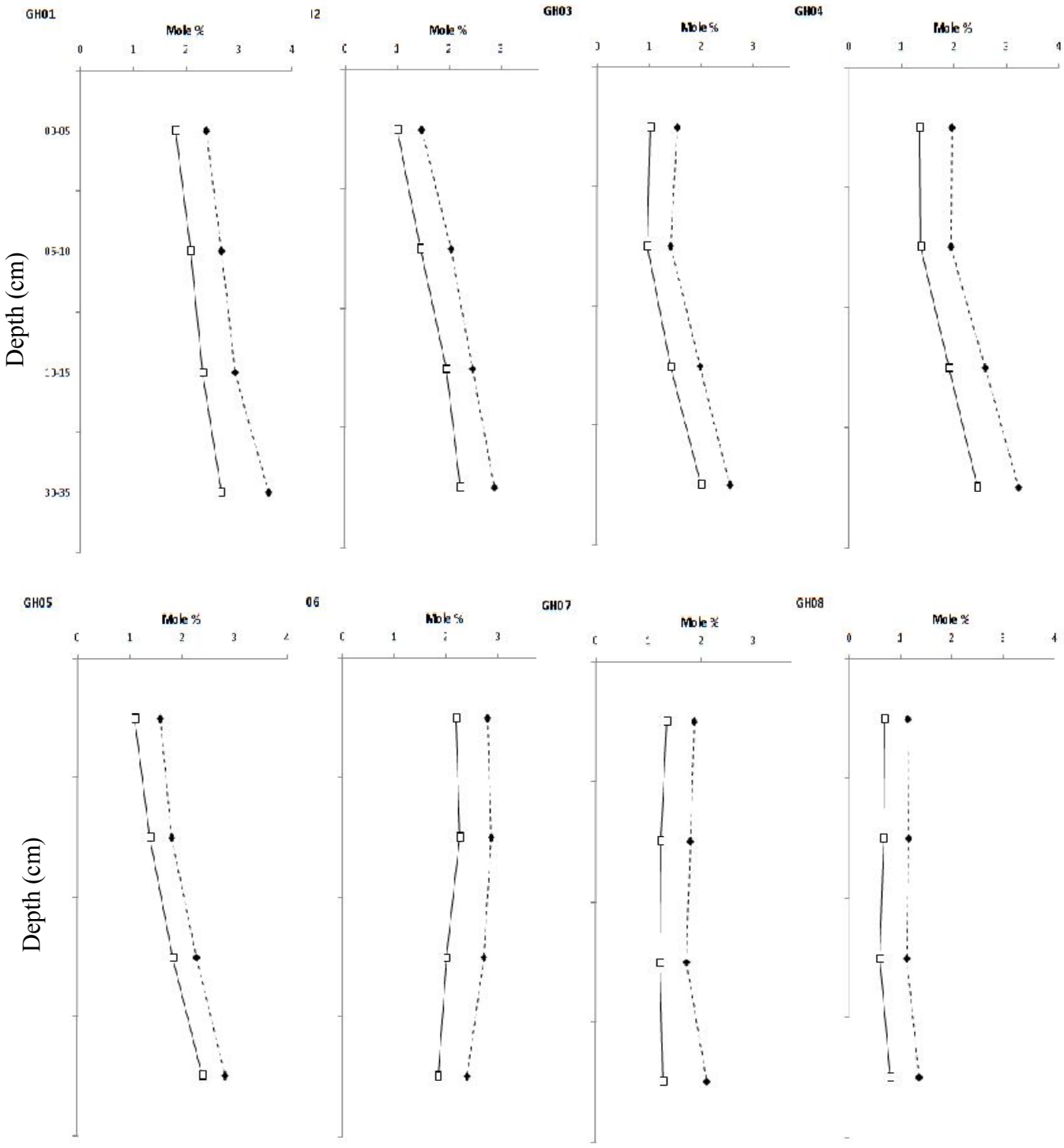


Figure 4.49: The downward variation of non-proteinaceous amino acids (β-Ala and γ-Aba) at each sampling site in the rainy seasons. ◆β-Ala; □γ-Aba .

4.7.2 Amino sugars

The amino sugars determined in this study include glucosamine (Gluam) and galactosamine (Galam) only. The mean content of both Gluam and Galam was *ca.* 265 $\mu g.g^{-1}$ in the dry season and 210 $\mu g.g^{-1}$ in the rainy season. In the dry season, the mean content of Gluam and Galam was 158 and 107 $\mu g.g^{-1}$, respectively. There were significant decreases in their concentration in the rainy season. Gluam decreased to 127 $\mu g.g^{-1}$ and Galam decreased to 83 $\mu g.g^{-1}$. Gluam averaged *ca.* 58% and Galam account for *ca.* 42% of the total determined hydrolysable hexosamines. The relative abundance of Gluam tended to decrease down-core while Galam increased with the sediment depths ($p > 0.05$). However, there seemed to be an accumulation of Gluam in 30-35 cm at GH08 (table 4.9).

The contributions of nitrogen from Gluam and Galam to the N pool are presented in the table 4.10. Gluam accounted for 1.66 and 1.45 % of the TN in the dry and rainy season, respectively. Galam contributed 1.15 and 0.99 % to the TN in the dry and rainy season, respectively. The N_{Gluam}:TN and N_{Galam}:TN did not significantly vary with depth ($p > 0.05$). Their contribution to the N pool was significantly higher in the dry season as compared to the rainy season ($p < 0.001$ for N_{Galam}: TN and $p < 0.05$ for N_{Gluam}: TN ratio). There were significant differences in their contribution to the N pool between the sampling sites ($p < 0.001$). Although a clear trend of variation was not seen along the transect, it seemed that the contribution of amino sugars to the N pool was low at the more alkaline sites (GH05, GH08), and higher at the dry and more saline sites (GH01, GH02 and GH04) (table 4.10).

Table 4.9: Relative abundance of Gluam and Galam in the sediments (mole %) at each site.

		Dry season		Rainy season	
Site	**Depth (cm)**	**GLUAM**	**GALAM**	**GLUAM**	**GALAM**
GH01	00-05	61.6	38.4	62.0	38.0
	05-10	60.1	39.9	60.5	39.5
	10-15	59.7	40.3	60.7	39.3
	30-35	57.5	42.5	58.0	42.0
GH02	00-05	61.7	38.3	63.4	36.6
	05-10	60.3	39.7	62.6	37.4
	10-15	59.2	40.8	59.6	40.4
	30-35	59.0	41.0	60.2	39.8
GH03	00-05	61.0	39.0	64.5	35.5
	05-10	59.7	40.3	62.9	37.1
	10-15	59.5	40.5	60.4	39.6
	30-35	58.1	41.9	59.9	40.1
GH04	00-05	61.4	38.6	61.5	38.5
	05-10	60.3	39.7	62.1	37.9
	10-15	59.6	40.4	61.3	38.7
	30-35	59.0	41.0	59.3	40.7
GH05	00-05	59.0	41.0	61.4	38.6
	05-10	59.0	41.0	59.1	40.9
	10-15	59.0	41.0	59.9	40.1
	30-35	60.4	39.6	59.8	40.2
GH06	00-05	59.8	40.2	58.5	41.5
	05-10	60.1	39.9	59.3	40.7
	10-15	59.1	40.9	58.5	41.5
	30-35	59.6	40.4	58.7	41.3
GH07	00-05	60.9	39.1	60.4	39.6
	05-10	60.8	39.2	60.3	39.7
	10-15	60.8	39.2	60.2	39.8
	30-35	56.6	43.4	51.4	48.6
GH08	00-05	47.4	52.6	50.9	49.1
	05-10	47.1	52.9	49.6	50.4
	10-15	49.0	51.0	49.9	50.1
	30-35	58.7	41.3	51.4	48.6

Table 4.10: Contribution of Gluam and Galam to the N pool (%) in the sediments at each site.

		Dry season		Rainy season	
Site	**Depth (cm)**	**GLUAM**	**GALAM**	**GLUAM**	**GALAM**
GH01	00-05	1.65	1.03	1.91	1.17
	05-10	1.58	1.05	1.74	1.14
	10-15	1.56	1.05	1.75	1.13
	30-35	1.51	1.12	1.71	1.24
GH02	00-05	1.90	1.18	1.48	0.85
	05-10	1.82	1.20	1.69	1.01
	10-15	1.73	1.19	1.75	1.19
	30-35	1.77	1.23	1.79	1.18
GH03	00-05	1.71	1.10	1.60	0.88
	05-10	1.74	1.17	1.58	0.94
	10-15	1.82	1.24	1.63	1.07
	30-35	1.72	1.24	1.12	0.75
GH04	00-05	1.95	1.23	1.82	1.14
	05-10	1.92	1.26	1.84	1.12
	10-15	1.84	1.24	1.94	1.22
	30-35	1.81	1.26	1.50	1.01
GH05	00-05	1.51	1.05	1.52	0.96
	05-10	1.54	1.07	1.12	0.77
	10-15	1.46	1.02	0.95	0.63
	30-35	1.59	1.04	1.19	0.80
GH06	00-05	1.84	1.24	1.03	0.74
	05-10	1.68	1.12	1.14	0.78
	10-15	1.93	1.33	1.22	0.87
	30-35	1.89	1.28	1.14	0.80
GH07	00-05	1.95	1.25	1.81	1.19
	05-10	2.38	1.54	1.86	1.23
	10-15	2.06	1.33	1.85	1.22
	30-35	1.61	1.22	1.12	1.02
GH08	00-05	0.95	1.06	1.26	1.20
	05-10	0.78	0.88	0.77	0.78
	10-15	0.73	0.75	0.87	0.87
	30-35	1.28	0.89	0.82	0.77

Gluam contents were used to calculate the content of chitin in the sediments, assuming that all chitin was hydrolyzed with 6N HCl and the hydrolyzation of 221 g chitin produces 179 g Gluam. The concentrations of chitin calculated from Gluam values (chitin~Gluam) are presented in table 4.11. The chitin~Gluam concentration tended to decrease down-core at the dry and saline sites (GH01, GH02 and GH04) and no clear down-core variation was found at the tidal-affected-sites. The differences between depths, however, were not statistically significant ($p > 0.05$).

In the dry season, the contribution of chitin~Gluam to the OC pool and TN in the sediments varied from 0.7 to 1.8 % and from 0.7 to 2.8 %, respectively. These ranges were extended in the rainy season: the contribution of $OC_{\text{-chitin~Gluam}}$ to the total OC varied between 0.4 and 7.7 % while the contribution of $N_{\text{chitin~Gluam}}$ to the TN varied from 0.5 and 4.5 %. Chitin calculated through the Gluam quantities seemed to be an important contributor to the pool of OM in the sediments at GH08 (figure 4.50 and 4.51). The contribution of $OC_{\text{-chitin~Gluam}}$ to the total OC and contribution of $N_{\text{chitin~Gluam}}$ to the TN did not vary significantly with depth ($p > 0.05$) and their down-core variation did not follow a clear trend even. No significant seasonal difference in these proportions of contribution was found in the sampling year ($p > 0.05$).

Table 4.11: Concentration of chitin~Gluam in the sediments ($\mu g.g^{-1}$) at each sampling site.

Site	Depth (cm)	Dry season	Rainy season
GH01	00-05	263.5	246.3
	05-10	201.2	179.9
	10-15	195.6	183.6
	30-35	185.7	180.7
GH02	00-05	306.0	260.3
	05-10	224.6	173.8
	10-15	166.0	157.8
	30-35	192.5	186.6
GH03	00-05	204.6	141.7
	05-10	217.2	161.5
	10-15	208.9	153.1
	30-35	243.6	114.5
GH04	00-05	245.7	221.3
	05-10	222.7	210.7
	10-15	187.0	190.4
	30-35	203.9	204.1
GH05	00-05	149.0	156.3
	05-10	213.5	139.1
	10-15	142.6	63.0
	30-35	195.3	112.1
GH06	00-05	224.1	118.2
	05-10	236.6	131.9
	10-15	180.7	89.9
	30-35	244.6	99.9
GH07	00-05	249.3	166.1
	05-10	299.8	203.6
	10-15	293.0	267.7
	30-35	92.1	55.9
GH08	00-05	36.2	31.2
	05-10	32.0	33.7
	10-15	18.4	11.3
	30-35	198.1	74.3

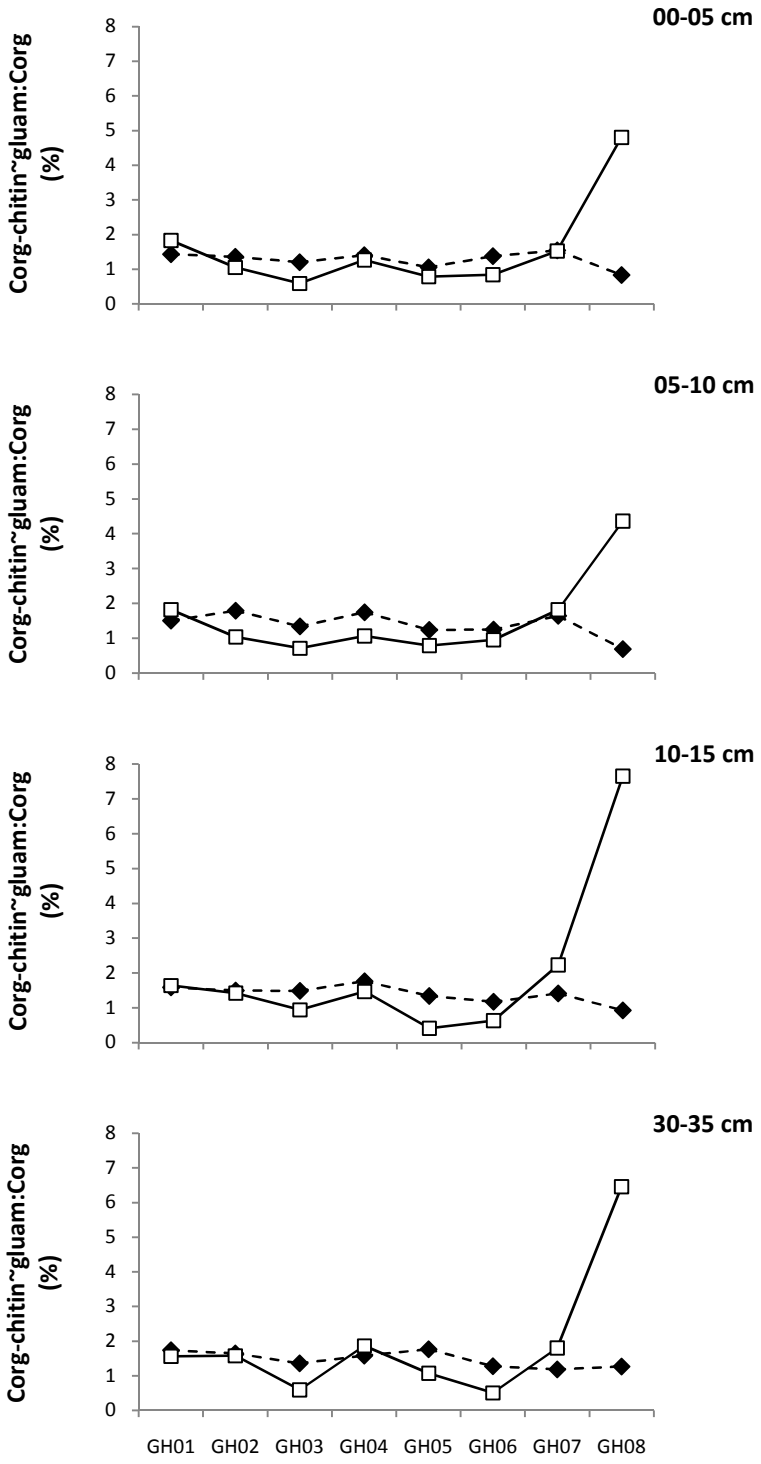


Figure 4.50: Contribution of chitin~Gluam to the OC pool in the sediments along the transect. ◆ dry, □ rainy season.

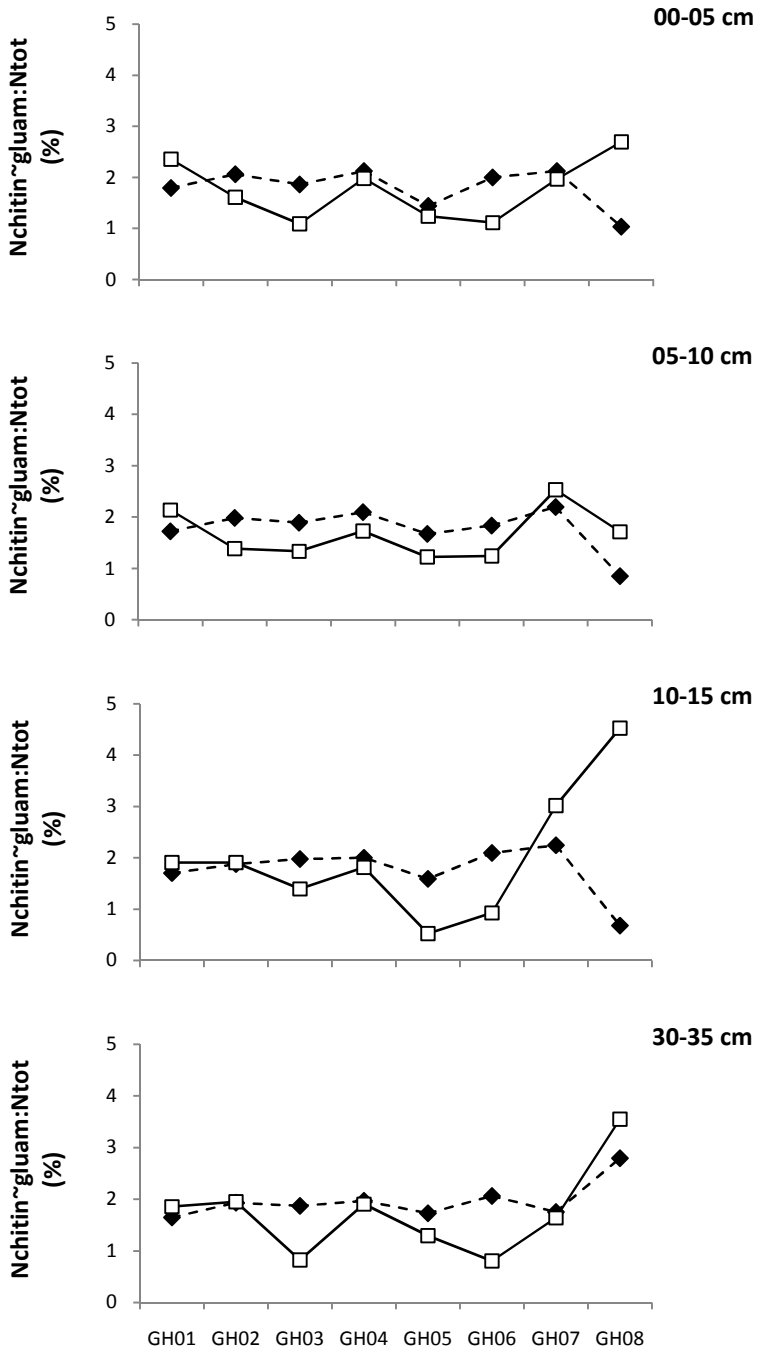


Figure 4.51: Contribution of chitin~Gluam to the N pool in the sediments along the transect. ◆ dry, □ rainy season.

4.8 Amino acids and amino sugars in plant materials

Galam was absent from the amino sugar composition in all plant materials. Glu, Asp, Gly and Ala were the most abundant amino acids in the plant materials. Tau, Orn and β-Ala were detected as traces only. The sediment conditions and seasonal changes did not affect the composition patterns of amino acids in the plant materials (figure 4.52).

The concentrations of THAA in plant materials were significantly different between the plant species ($p < 0.001$). The mean concentration of THAA was lowest in *Sesuvium* and highest in *Avicennia* but there was no significant difference between *Avicennia* and *Lumnitzera* (figure 4.53 and 4.54). The mean THAA concentration was significantly higher in the dry season ($p < 0.01$) and similar between the plant species ($p > 0.05$).

The contribution of C_{aa} to OC pool in the plant materials was significantly different between the plant species ($p < 0.01$). It was highest in *Avicennia* and lowest in *Sesuvium* in the dry season (figure 4.55). However, in the rainy season, the highest contribution of C_{aa} to the OC pool was found in *Sesuvium* leaves (figure 4.56). *Sesuvium* stems contained a significantly lower proportion of C_{aa} to OC, in the comparison with the leaves ($p < 0.001$). On the contrary, the contribution of N_{aa} to TN in plant materials was significantly different between the plant materials ($p < 0.001$). It was highest in *Lumnitzera* in both sampling seasons (figure 4.57 and 4.58). In the rainy season, the lowest contribution of N_{aa} to the TN was found in *Avicennia* leaves (figure 4.58). In contrast, the difference in N_{aa} contribution to the TN between the leaves of *Avicennia* and *Sesuvium,* as well as the difference between the *Sesuvium* stem and leaves, were negligible in the dry season (figure 4.57).

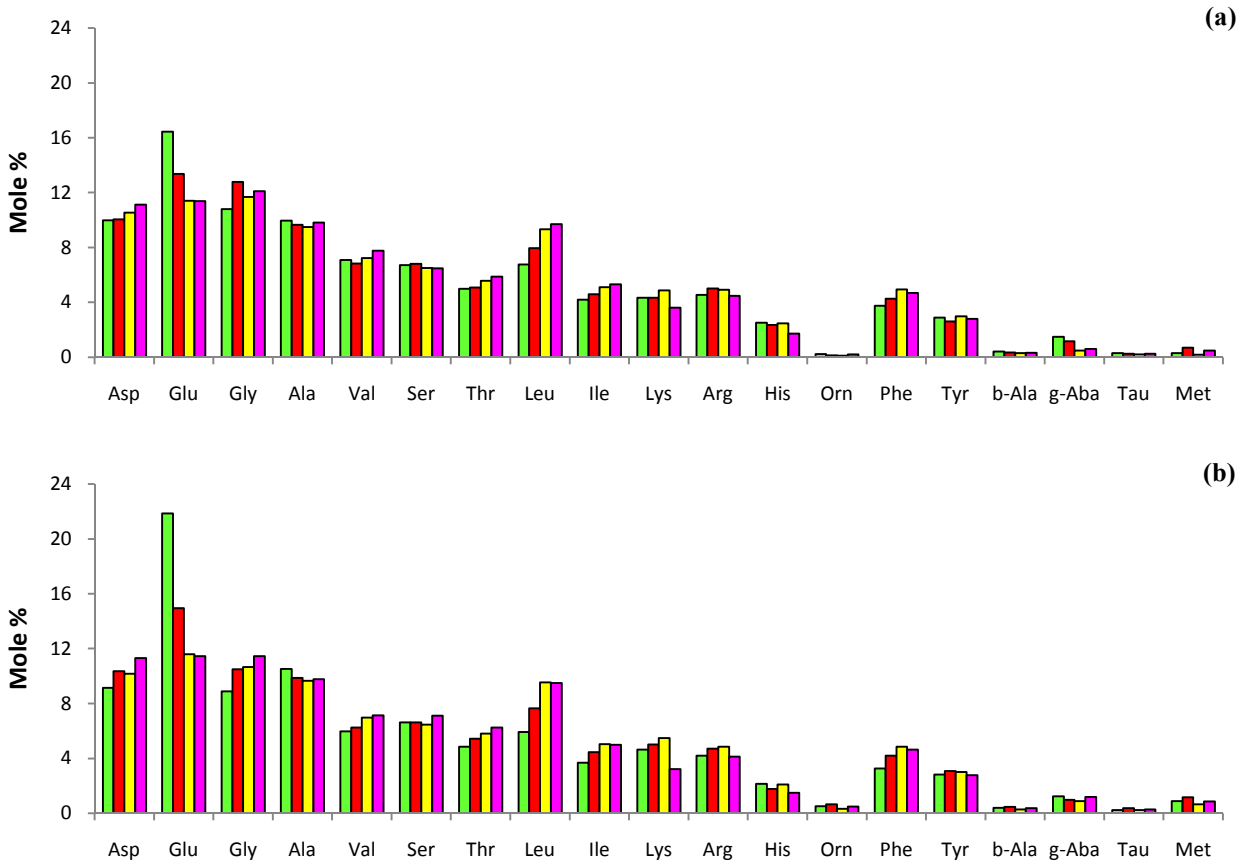


Figure 4.52: Composition pattern of amino acids in plant materials in (a): dry season and (b): rainy season. *Sesuvium* stems, *Sesuvium* leaves, *Lumnitzera* leaves and *Avicennia* leaves, respectively.

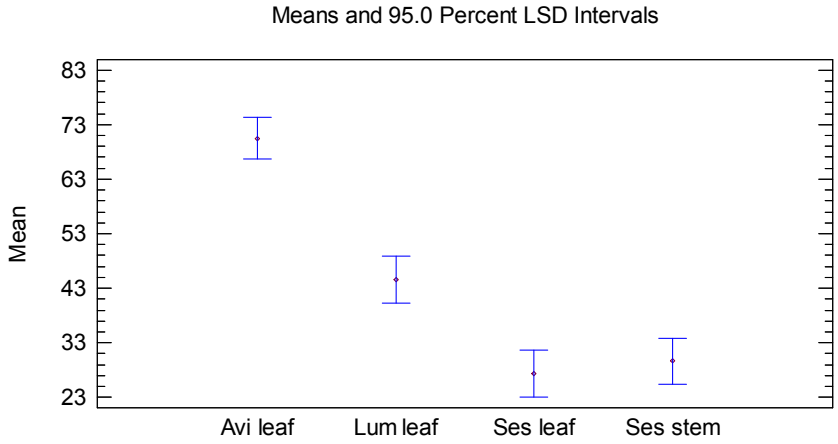


Figure 4.53: Mean comparison of THAA concentration (mg.g^{-1} dry weight) in plant materials collected in the dry season.

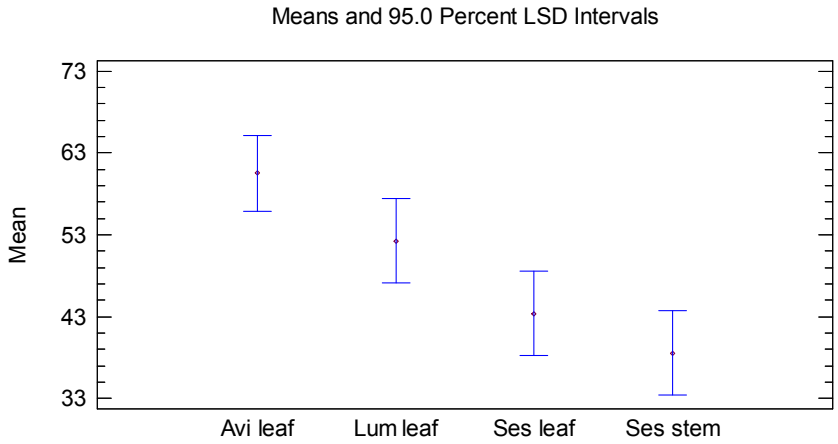


Figure 4.54: Mean comparison of THAA concentration (mg.g^{-1} dry weight) in plant materials collected in the rainy season.

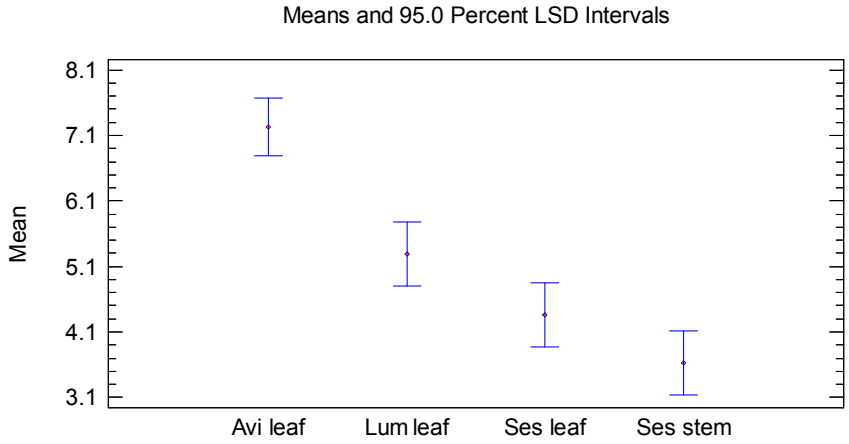


Figure 4.55: Mean contribution of C_{aa} to OC pool (%) in plant materials collected in the dry season.

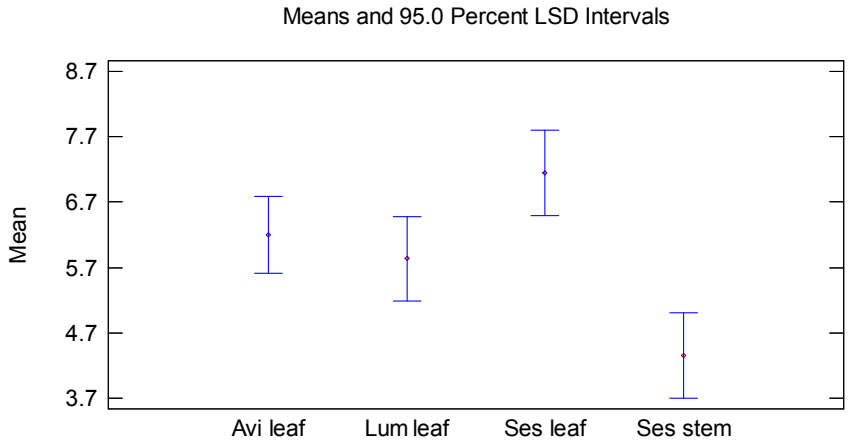


Figure 4.56: Mean contribution of C_{aa} to OC pool (%) in plant materials collected in the rainy season.

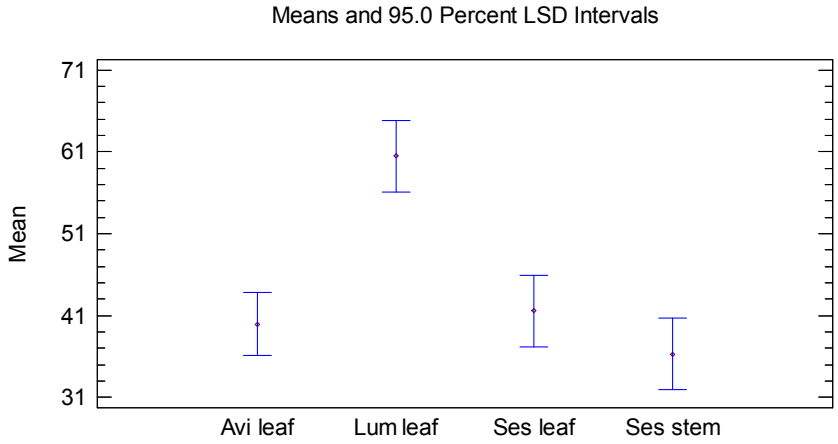


Figure 4.57: Mean contribution of N_{aa} to TN pool (%) in plant materials collected in the dry season.

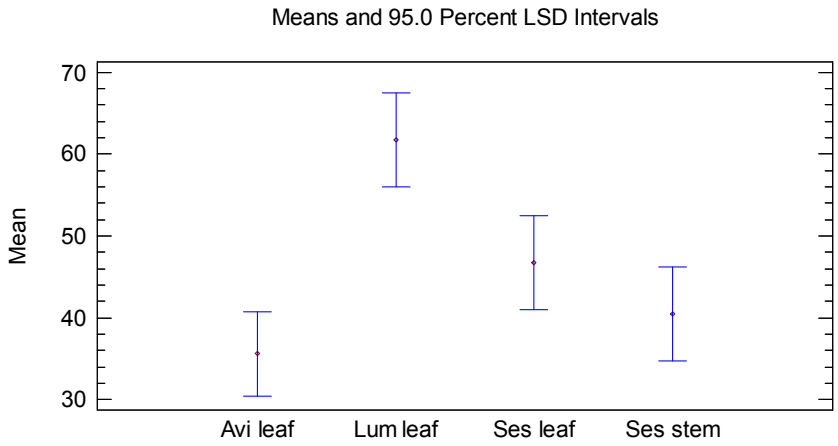


Figure 4.58: Mean contribution of N_{aa} to TN pool (%) in plant materials collected in the rainy season.

5 DISCUSSION

5.1 Sediment nutritional state along the ecotone

Due to the effects of monsoon, the study area is subject to complicated erosion and deposition processes (Le *et al*. 2012) which were partly revealed in the down-core distribution of the grain size in this study. The site GH05 is a deteriorated wall of the salt-pan. Therefore, it probably prevented the interior area from the influences of sea water and resulted in the accumulation of the medium sands at this site in 5-10 cm (figure 4.1), which might refer to strong erosion in the past. The high energy of waves and tidal action during that period probably led to the higher percentage of fine sand at GH03 compared to the other sites behind the wall. In the recent time, the erosion probably has been reduced as the medium sand seemed to be blocked at GH08 in the surface layer. A study on geology and sediment structure in the Lower Mekong Delta basin claimed that the deposition in Ganh Hao was interrupted. At present, the study area is deposited with the rate is of ca. 2.07 cm. y^{-1} (Le *et al*. 2012).

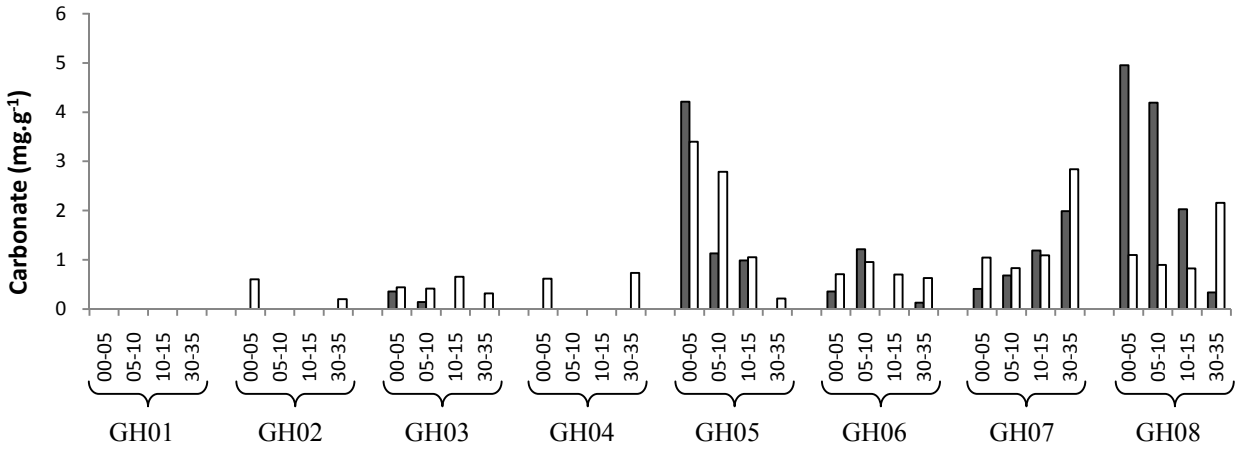


Figure 5.1: Carbonate distribution in the sediments. ■dry, □rainy season.

The distribution of grain sizes and tidal inundation are the factors which control the characteristics of the sediments. The low humidity at GH08 might result from the high percentage of coarse grains (figure 4.1), in spite of the high inundation level and frequency at this sand flat. GH01, GH02 and GH04 were the salt-pan and in the sampling year, they were less affected by the tidal water. Consequently, when the values of humidity recorded at these sites were eliminated, a significant correlation between the sediment humidity and percentage of silt–clay fraction was found ($p < 0.01$, $r = 0.57$).

The topographical slope probably prevented the trespassing of sea water on the sites GH01, GH02 and GH04 from the shallow creek (GH03) (figure 2.2). The relative isolation from tidal water resulted in the salt accumulation in the sediments of these three sites during the dry season. Saline water which infiltrated into the sediments during the periods of salt production moved up through capillarity and salts accumulated in the surface sediments (Chhabra 1996, Fujimaki *et al*. 2006). The low density of plants can promote the evaporation (Smith 1987, Passioura *et al*. 1992) and result in the extremely high sediment salinity of tropical estuaries and mangrove-salt flats ecotones (Wolanski 1986, Hollins and Ridd 1997). Accordingly, the highest salinity values were recorded at GH01 and GH04. In the surface sediment at GH02, the salinity was lower than GH01 and GH04 though this site was also a part of the salt-pan (Vu pers.comm.). This finding can be attributed to the cover of *Avicennia lanata* at GH02 (figure 2.2). In the dry season, the salinity of the surface layer at GH01 and GH04 was 69.5 ‰ and 60.7 ‰, respectively, while it was only 24.7 ‰ in the same layer at GH02.

In the rainy season, the down-core decreases in salinity were recorded at all sampling sites, indicating that the salt-washing had taken place in the upper layers of the whole study area. The intrusion of rainfall water towards the deep layers was limited because of the high percentage of the fine grains at GH01 and GH04 (figure 4.1). Consequently, the difference in salinity between the dry and rainy season at these sites was much more obvious in 0-5 cm (figure 4.3). Due to the influence of tidal water, a significant negative correlation between the sediment humidity and salinity was recorded

from the sites GH01, GH02 and GH04 only ($p < 0.05$, $r = -0.70$). The seasonal difference in salinity at the layers beneath 5 cm was negligible.

The elevation at GH05 is the cause of bivalve shells accumulation at this site, which in turn resulted in the high pH in the surface sediment (figure 4.4). The distribution of carbonate along the transect (figure 5.1) shows that it was transported to the interior sector from GH08 by tidal waters and blocked at GH05. Carbonate trace (0.36 $mg.g^{-1}$) in the surface sediment at GH03 is a proof of its transportation to this site. However, tidal water could not reach GH01, GH02 and GH04 in the dry season. In the rainy season, carbonate data shows that tidal water could reach GH02 and GH04 only. The carbonate content, therefore, affected the sediment pH at GH03, GH05, GH06, GH07 and GH08 ($p < 0.001$, $r = 0.71$).

Within 0-10 cm, the pH values at GH04 and GH05 were almost identical and close to the values recorded at GH06 (figure 4.4). This can be attributed to the influence of sea water on the sediment at GH04 in the past. During the period of strong erosion, sea water probably intruded into GH04. Nevertheless, the low percentage of coarse grains and the absence of carbonate at GH04 (figure 5.1) did not support this argument. Tidal water probably reached GH04 through rising from GH03 rather than crossing GH05. The lower energy of tidal water in the creek might result in the carbonate trace in GH03 (figure 5.1).

In the upper layers (0-15 cm), the pH values were quite stable in the whole study area in the rainy season. The variation trend along the transect was not as evident as in the dry season, except the increase in pH from GH06 to GH08 (figure 4.4). The buffering influence of seawater compensated the rainfall-driven changes in pH and resulted in the stability of pH in the rainy season. The remarkable difference in pH values between the dry and rainy season was found in the surface sediment at GH01. The pH value in the rainy season was 1.2 times higher than the value recorded in the dry season. GH01, GH02 and GH04 were used for salt production. Therefore, these sediments were compressed and smoothened to avoid the infiltration of saline water. Thus, these sediments were reduced and resulted in the high concentration of H_2S, which in turn caused the low pH

(Pomeroy and Wiegert 1981, Bradley and Morris 1990). Nevertheless, the pH values at GH02 and GH04 in the dry season were not significantly different from GH03 and GH06, which were inundated by the tidal water more frequently. The human activities in the soil preparation for *Lumnitzera* plantation at GH04 and *Avicennia* plantation at GH02 probably reduced the H_2S concentration and favored the oxygenation in these sediments. Consequently, the pH values at these sites increased.

At GH01, there was the natural invasion of *Sesuvium* only. The low coverage at this site promoted the evaporation from the sediment (Smith 1987, Passioura *et al*. 1992) and let the sediments be drier. The low humidity at GH01 in the dry season (23.4 %) might relate to the low pH value (6.3). Furthermore, high salinity is also a reason of the low pH. Kissel *et al.* (2009) claimed that the measured sediment pH decreased with the increase in salt concentration. Camberato and Joern (2012) found that soil pH increased when the humidity increased. The results in Ganh Hao show a significant correlation between the sediment pH and humidity when those values from the sites with high carbonate contents (GH05 and GH08) were eliminated ($p < 0.05$, $r = 0.47$).

Due to the organic adhesive on the large contact surface of the fine grains (clay and fine silt), they can easily aggregate to form the blocks. Thus, the cracks were created in the sediments under the dry condition. These cracks, in turn, allowed air intrusion into the sediments and resulted in the positive Eh values even at the deep layers (30-35 cm) (figure 4.5). The cracks on surface sediments resulted in the higher Eh values at the sites which were less affected by the tidal water compared to the sites dominated by the medium sand (figure 4.5).

The aerobic condition of the sediments promoted the turnover rate of OM and resulted in the higher pH values in comparison with other saltpans and salt-marshes. The average pH values at each depth interval in Ganh Hao were *ca*. 7 and reached *ca*. 7.3 in the surface sediments (table 4.1). The pH of a saltpan recorded by Kamat and Kerkar (2011) in Goa was 6.5 and 7.1 in the summer. The range of pH variation in a salt-marsh in Delaware was from 5.5 and 7 (Luther *et al*. 1992). In an abandoned salt-pan in Can

Gio, which was covered by *Sesuvium portulacastrum* and planted *Ceriops*, the sediment pH values were less than 6.1 (Tran 2007). The difference in pH between Ganh Hao and Can Gio probably resulted from the nature of the sediments. Can Gio develops on an acid sulfate substrate which contains a high level of aluminous materials (Thuyen pers. comm.).

The redox-potential controls microbial activities which decompose OM (Stumm 1978). Consequently, the sedimentary nutritional state is significantly affected by Eh. The NH_4^+ content in sediment is influenced by OM degradation, excretion of benthic macrofauna, nitrification and microbial uptake (Fenchel and Blackburn 1979). In the surface sediments, the high NH_4^+ contents were recorded at GH01, GH02 and GH07 in the dry season (figure 4.8). GH01 and GH02 were occupied by *Sesuvium portulacastrum*, which was proved to be able to ameliorate the N level in sediment (Tran 2007). This ability was attributed to the fixation of atmospheric N mediated by arbuscular mycorrhiza (Schmitt 2006). The N fixation probably resulted in the high content of NH_4^+ at these two sites. Furthermore, the light acidic pH in the sediments at GH01 and GH02 might drive to the accumulation of NH_4^+ while the high pH at GH05 promoted the NH_4^+ oxidization (Khalil *et al.* 2005) and led to its low content. Within 5-10 cm, the NH_4^+ contents decreased from GH01 to GH04 corresponded with the increase in pH. The reverse correlation between the NH_4^+ content and pH was reported by Kusum and Aranuchalam (2001), Aciego-Pietri and Brookes (2008).

Due to the predominance of clay and fine silt in the sediments at GH06 and GH07, along with the higher inundation frequency and level, these sediments were more reduced (figure 4.5). Therefore, the OM degradation was limited at these sites. Moreover, the pH value at GH07 was *ca.* 7.5. Thus, the NH_4^+ content at GH07 was expected to be lower than the interior sites which were more aerated. Nevertheless, the highest NH_4^+ contents in the study area were recorded at GH07 in both seasons (figure 4.8). The mud flat is subject to an intermittent drying and wetting due to the tidal inundation. The sediment cores were taken in the dry period when the mud flat was exposed. The N mineralization

in this period was probably stimulated and hence, the mobility of N increased (Venterink *et al.* 2002). The increase in N mineralization when wet soils are drained and aerated was reported by Birch 1960, Bridgham *et al.* 1998, Cabrera 1993, Updegraft *et al.* 1995). The high NH_4^+ content at GH07 could be a factor resulting in the natural regeneration of *Avicennia lanata* at this site. NH_4^+ is an important source of N for plant growth and regeneration (Salsac *et al.* 1987).

The NH_4^+ contents in the rainy season were higher than in the dry season at most of the sampling sites, with an exception seen at GH01 (figure 4.8). Within 0-10 cm, the NH_4^+ content at GH01 in the dry season was 1.5 times higher than in the rainy season. The difference in pH between the dry and rainy season at GH01 was remarkable (figure 4.4) (20% in 0-5 cm, 8 and 10% in 5-10 cm and 10-15 cm, respectively). The high pH in the rainy season probably resulted to the low NH_4^+ contents as it was oxidized (Khalil *et al.* 2005). The higher NH_4^+ contents at the other sites might relate to the sediment bacteria. Nguyen (2011) found *Vibrio aesturianus* at most of the sampling sites in the rainy season, except GH01 and GH02. The ability of this bacterium in N fixation was claimed by Holguin *et al.* 2001. *V. aesturianus* is common in aquatic environments and coastal waters (Thompson *et al.* 2004). The wider inundated area in the rainy season (Vu pers. comm.) brought the study area to a milder condition, *i.e.* higher humidity and lower salinity. Thus, *V. aesturianus* was more abundant in the rainy season (Nguyen 2011). Their ability in N fixation could have led to the higher NH_4^+ content in the rainy season compared to the dry season.

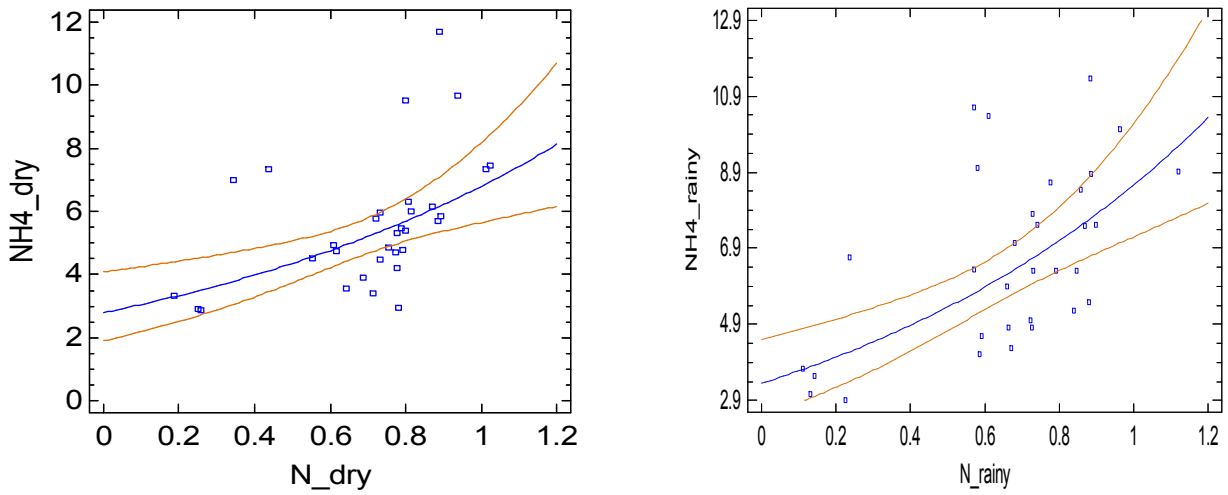


Figure 5.2: The correlation between N and NH_4^+ in the dry and rainy season, $p < 0.01$, $r = 0.54$ in the dry season and $p < 0.001$, $r = 0.64$ in the rainy season.

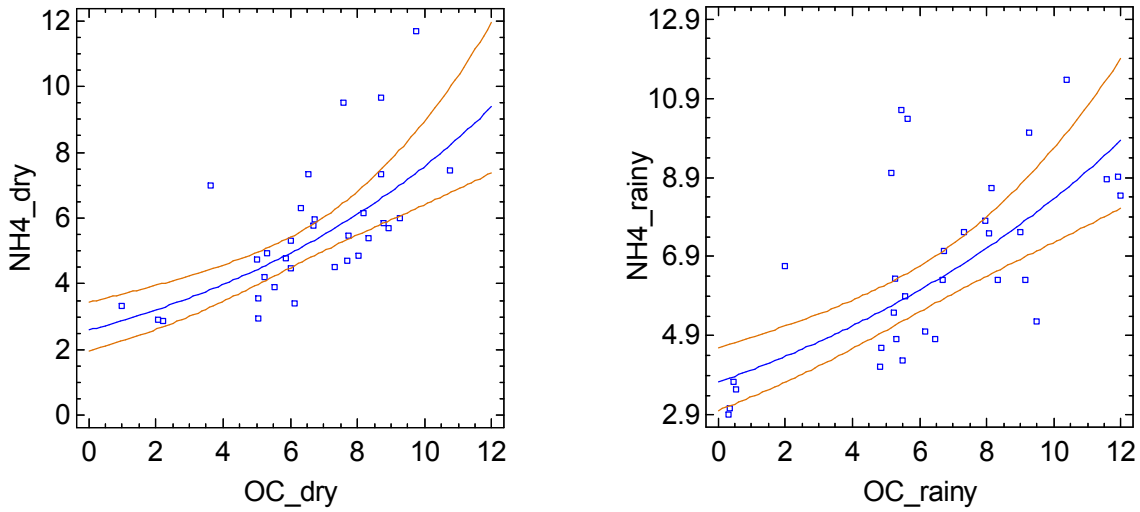


Figure 5.3: The correlation between OC and NH_4^+ in the dry and rainy season, $p < 0.0001$, $r = 0.70$ in the dry season and $p < 0.0001$, $r = 0.71$ in the rainy season.

In addition to N fixation, NH_4^+ can be also produced by OM decomposition. In the whole study area, the OC and N content were higher in the rainy season than in the dry season (figure 4.11), except GH07 and GH08. These exceptions corresponded with the higher NH_4^+ contents. The ammonification was probably promoted by the supplement of OM. This finding was supported by the significant correlation between OC, N and NH_4^+ content in both seasons (figure 5.2 and 5.3). Burger and Jackson (2003) claimed that OM inputs gradually liberate NH_4^+. Schnitzer and Khan (1978) found that NH_4^+ may accumulate in soils with low water contents due to the inhibited nitrification. However, in Ganh Hao, the NH_4^+ contents increased with the increase of the sediment humidity ($p < 0.001$, $r = 0.62$ and 0.70 in the dry and rainy season, respectively). The correlations suggest that NH_4^+ content in the study area was probably strongly influenced by sediment bacteria, whose abundance is controlled mostly by sediment humidity.

The absence of vegetation at GH08, along with the abundance of sand fraction in the sediment, is likely the reason for the low OC and N content at this site in comparison with the other sites (figure 4.11). Nevertheless, the drastic increase in OC and N in 30-35 cm at this site in the dry season might refer to an accumulation of OM in this depth, which was probably linked to the reduced condition of the sediment (figure 4.5). The OM deficiency and the predominance of sand are the reasons for the low NH_4^+ content at GH08 within 0-15 cm. In the depth of 30-35 cm, the NH_4^+ content at GH08 was higher than 7.5 $ug.g^{-1}$ corresponding to the negative Eh value in the dry season. In the anaerobic environments, NO_3^- is reduced to form NH_4^+. Therefore, the level of NH_4^+ increases in the anoxic sediments (Buresh and Patrick 1978).

In the depth of 30-35 cm in the whole study area, the NH_4^+ content tended to increase towards the inundated sites in both seasons. The inverse relationship between grain size and OM content was recorded by Hargrave (1972), Dale (1974), de Flaun and Mayer (1983), Meyer-Reil (1986), Mayer (1994). The low content of NH_4^+ at the sandy sediments was claimed by Dorota and Halina (2001).

The total content of NO_3^- and NO_2^- in Ganh Hao varied between 0.56 and 5.04 $ug.g^{-1}$. The values from the abandoned salt-pan (GH01 and GH02) were lower compared to the study of George and Antoine (1982). This finding probably resulted from the rapid denitrification which caused the N loss. The denitrification tended to be faster towards the sea in the dry and rainy season (figure 4.7). In agreement with George and Antoine (1982), this study showed that NO_3^- and NO_2^- levels were higher at the vegetated sites (GH01 and GH04).

In accordance with Garcia (1974), the NO_3^- concentration increased with the increasing of the soil pH. However, the sediment pH values at the site GH05, GH07 and GH08 were higher than 7.5 in the dry season, corresponding with the low concentration of NO_3^- and NO_2^-. This finding suggested that the denitrification was supported by the alkaline pH. These results are in the agreement with George and Antoine (1982). Nevertheless, this agreement was restricted to the flooded sector. In the dry sector (GH01, GH02 and GH04), the concentration of NO_3^- and NO_2^- at these sites were higher due to the low pH. Similarly, the sediment pH at GH04 and GH05 beneath 5 cm was not remarkably different in both seasons. Meanwhile, the concentration of NO_3^- and NO_2^- at GH04 was considerably higher than GH05. There was a significant relationship between the sediment salinity and the concentration of NO_3^- plus NO_2^- throughout the sampling year ($p < 0.05$; $r = 0.35$ in the dry season and $p < 0.001$; $r = 0.58$ in the rainy season). The sediment salinity probably precluded the denitrification in the sediment (Seo *et al.* 2008) through reducing the diversity of NO_2^- reductase gene in denitrifying bacteria (Yoshie *et al.* 2004).

The content of AP in Ganh Hao varied between 0.0075 and 0.021 $mg.g^{-1}$ dry weight of the sediments. This range is in agreement with Oxmann *et al.* (2010) and Tran (2007) concerning the AP contents in mangroves in Can Gio. However, the AP content in Ganh Hao was lower compared to the results of Mendoza *et al*. (2011). The AP content in the dry season exhibited a highly significant correlation with the sediment Eh ($p < 0.05$, $r = -0.41$). This significant inverse correlation indicated the important contribution of

phosphate reduction from P-Fe/Al compounds to the quantity of AP in Ganh Hao. Liberation of AP in the anoxic sediments was reported by Shapiro (1958), Silva and Sampaio (1998), Mendoza (2007).

Within 0-15 cm, the AP content did not vary remarkably along the transect though their peaks were seen at GH01, GH04 and GH07 (figure 4.9). The difference in AP content between the dry and rainy season at each sampling site was not significant. An exception was recorded in 0-10 cm at GH08. The AP content in the dry season was 3 times higher than in the rainy season in 0-5 cm. The difference in 5-10 cm was 2 times. Due to the totally absence of vegetation, the OM content at GH08 was the lowest value in the study area. Moreover, the predominance of sand and high level of carbonate at this site may restrict the P mineralization as the phosphate solubilizer population in these sediments is poor (de Souza *et al.* 2000). In addition, the C:P ratio at GH08 was very low (*ca.* 5). This result shows that GH08 was subject to a serious deficiency of OC and P. Thus, AP in the sediment could be absorbed by the sediment microorganisms (Espinoza *et al.* 1914). The drastic decrease of OM within 0-10 cm at GH08 in the rainy season compared to the dry season probably limited the microbial-mediated degradation of OM and mineralization of P in the rainy season. The absence of vegetation could also explain the lowest AP content at GH08. Plants can excrete organic acids to solubilize phosphate and hence, improve their nutrient acquisition in carbonate sediments (Long *et al.* 2008). In addition, organic compounds in plant root exudates can promote the intrusion and development of mycorrhizal fungi in roots which are essential for phosphate uptake (Dakora and Phillips 2002).

In the aerobic zone, AP content can be influenced by the sediment bacteria. Phosphate solubilization can be conducted by various sediment bacteria (Rodriguez and Fraga 1999, Vazquez *et al*. 2000, Bashan and Holguin 2002, Bashan and Bashan 2005, Chen *et al*. 2006, Ivanova *et al*. 2006, Khan *et al*. 2009). Low-molecular-weight organic acids liberated by phosphate solubilizing bacteria (Goldstein 1995, Kim *et al.* 1997) chelate the cations that bind to P and convert it into soluble forms (Kpomblekeu and

Tabatabai 1994). The peaks of AP were seen at GH01, GH04 and GH07 in both seasons (figure 4.9). Nguyen (2011) found *Enterobacter* within 0-15 cm at GH05 and GH07 in both seasons in the same sampling year. This bacteria was demonstrated to be able to solubilize mineral phosphate (Kim *et al.* 1998, Vazquez *et al.* 2000, Ahemad and Khan 2010, Shahid *et al.* 2012). However, the high content of carbonate at GH05 probably limited their activity on phosphate solubilization. The effect of carbonate on phosphate solubilization in this circumstance is separated from the sediment pH, as the pH values at GH05 and GH07 were similar to each other (figure 4.4). The adsorption of P on the carbonate grains (De Kanel and Morse 1978, McGlathery *et al.* 1994) probably protected them from the activity of the phosphate solubilizer. Nguyen (2011) found *Vibrio proteolyticus* at GH01 and GH04 at the same sampling time. Moreover, the peaks of AP content at GH01, GH04 and GH07 in the rainy season corresponded with the abundance of *Bacillus* (Nguyen 2011). *V. proteolyticus* and *Bacillus* spp. can solubilize the phosphate minerals (Vazquez *et al*. 2000, Bashan and Holguin 2002).

The air diffusion likely resulted in the non-significant difference in AP contents among depths in the dry season. In 30-35 cm, the peaks of AP content were seen at GH03, GH06 and GH07 (figure 4.9) corresponded with the negative value of Eh. This finding agreed with Fekete *et al*. (1976) that the AP level was higher in the anoxic sediments. The fluctuations of AP content along the transect were almost identical within 0-15 cm in the dry and rainy season (figure 4.9). However, in the rainy season, at GH07, there was a decrease of *ca.* 39% in the AP content as compared to the dry season. This finding probably resulted from the strong regeneration and growth of *A. lanata* at this site in the rainy season. Oxmann *et al.* (2010) recognized that the AP content in the deep layers (30-40 cm) significantly affected the P content in leaves, indicating a preferential P uptake from the deep sediment by vegetation.

In agreement with Chen & Twilley (1999), this study found significant correlations between NH_4^+ and AP concentration in the dry and rainy season within 0-15 cm (figure 5.4). The requisition of ammonium for phosphate solubilization was recorded

by Asea *et al*. (1988). As mentioned above, the rapid denitrification likely resulted in the loss of N from the system. Consequently, the phosphate solubilization in Ganh Hao propably depended on the ammonification mediated by microbes. This finding was advocated by the low N:P ratios in the sediment. The deficiency of N in hypersaline areas was claimed by Whitney *et al*. (1981) and Seneca and Broome (1992). Consequently, N may become a serious limiting factor for bacteria rather than P. NH_4^+ is a major source of N for marine sediment bacteria (Hoch *et al*. 1992, Middelburg and Nieuwenhuize 2000). Hence, NH_4^+ can also limit the activities of the sediment bacteria, for instance, the microbial mediated phosphate solubilization. Although correlation does not necessarily imply causality, the correlations might reflect a complex interaction between the sediment conditions, as well as their qualities, and activities of sediment microbes in the N mineralization and P mobilization.

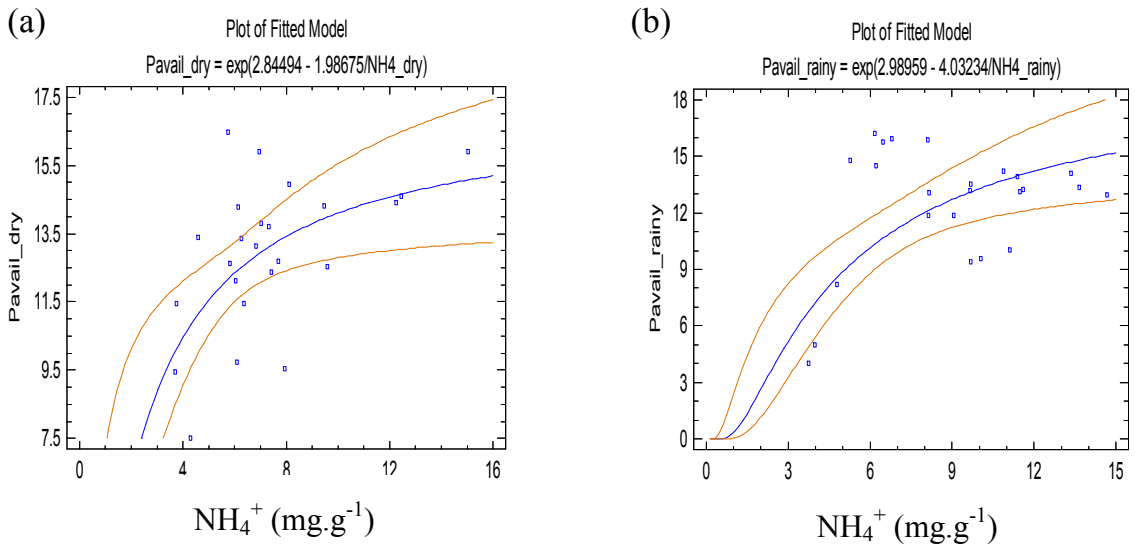


Figure 5.4: Correlation between NH_4^+ and AP concentration in (a): the dry season and (b): rainy season ($p < 0.01$). The correlation coefficient in the dry and rainy season were 0.5542 and 0.6307, respectively.

The OP concentrations did not exceed 15% of the TP in Ganh Hao. OP contributed 20-90 % of the TP in the surface layer of most soils. The predominance of IP

against the OP was in the agreement with Fabre *et al*. (1999), but contrary to Hesse (1962), Boto (1988) and Alongi *et al.* (1992). The low OP:TP ratio was claimed by Silva and Mozeto (1997). The variation range of TP in Ganh Hao was wider than in a mangrove in Pichavaram, India. The TP content in Ganh Hao varied between 370 and *ca.* 970 $\mu g.g^{-1}$ while this range was from 459 to 736 $\mu g.g^{-1}$ in Pichavaram mangrove (Prasad and Ramanathan 2010).

The IP content within 0-15 cm did not strongly fluctuated along the transect, except the peaks seen at GH05 and GH08. Probably due to the high carbonate level at these sites, more P was immobilized in the Ca-P complex. Fabre *et al.* (1999) claimed that IP content was high in dead mangrove at the hinterland and decreased in the pioneer mangrove at the mud flat. The decrease was attributed to desorption of P from sediment grains caused by the resuspension by tides. This can explain the lowest IP content at GH07 (figure 4.13). The high OP level at the vegetated sites agreed with Fabre *et al.* (1999), probably because of the high OM content in the sediments.

The IP:OP ratio tended to increase from GH01 towards GH05 in the dry season (figure 5.6) due to a higher concentration of IP. The IP:OP ratio was significantly correlated to the sediment pH ($p < 0.01$, $r = 0.68$ in the dry season and $p < 0.05$, $r = 0.40$ in the rainy season). The influence of pH on the mineralization of P was demonstrated by Thompson *et al*. (1954), Mandal and Islam (1978) and Harrison (1982) and it was attributed to the recalcitrant character of OP when the soil pH decreased (Enwezor 1967). In addition, the P mineralization in Ganh Hao was probably also controlled by the carbonate contents in the sediment, as there were significant correlations between the IP:OP ratio and the carbonate concentration ($p < 0.01$, $r = 0.50$).

The high values of IP:OP ratio at GH05 and GH08 in the surface sediments probably were resulted from the abundance of Ca-P complex. However, in the surface sediments, despite the similar carbonate concentration, the value of IP:OP ratio at GH07 was remarkably lower compared to GH06 (figure 5.6), indicating a lower mineralization of P at this site. The relationship between OC and IP concentration in the dry season

(figure 5.5) probably reflected the influence of sediment microorganisms on P mineralization, as OC was utilized as a source of energy for bacteria taking place in the mineralization of P (McGill and Cole 1981), inducing the decrease in OC level with increasing concentration of IP. However, in the rainy season, the level of OC was not correlated to the concentration of IP, probably due to the elevated microbial biomass (Nguyen 2011).

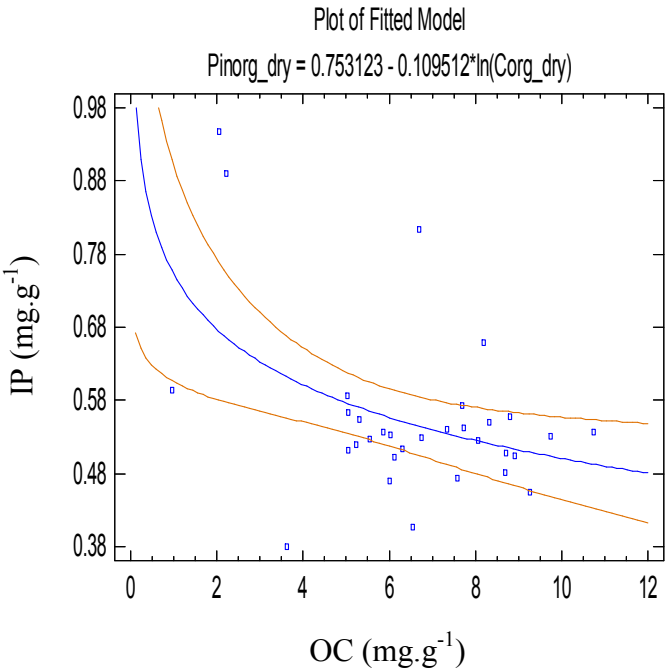


Figure 5.5: Correlation between the content of OC and IP concentration in the dry season ($p < 0.01$, $r = -0.46$).

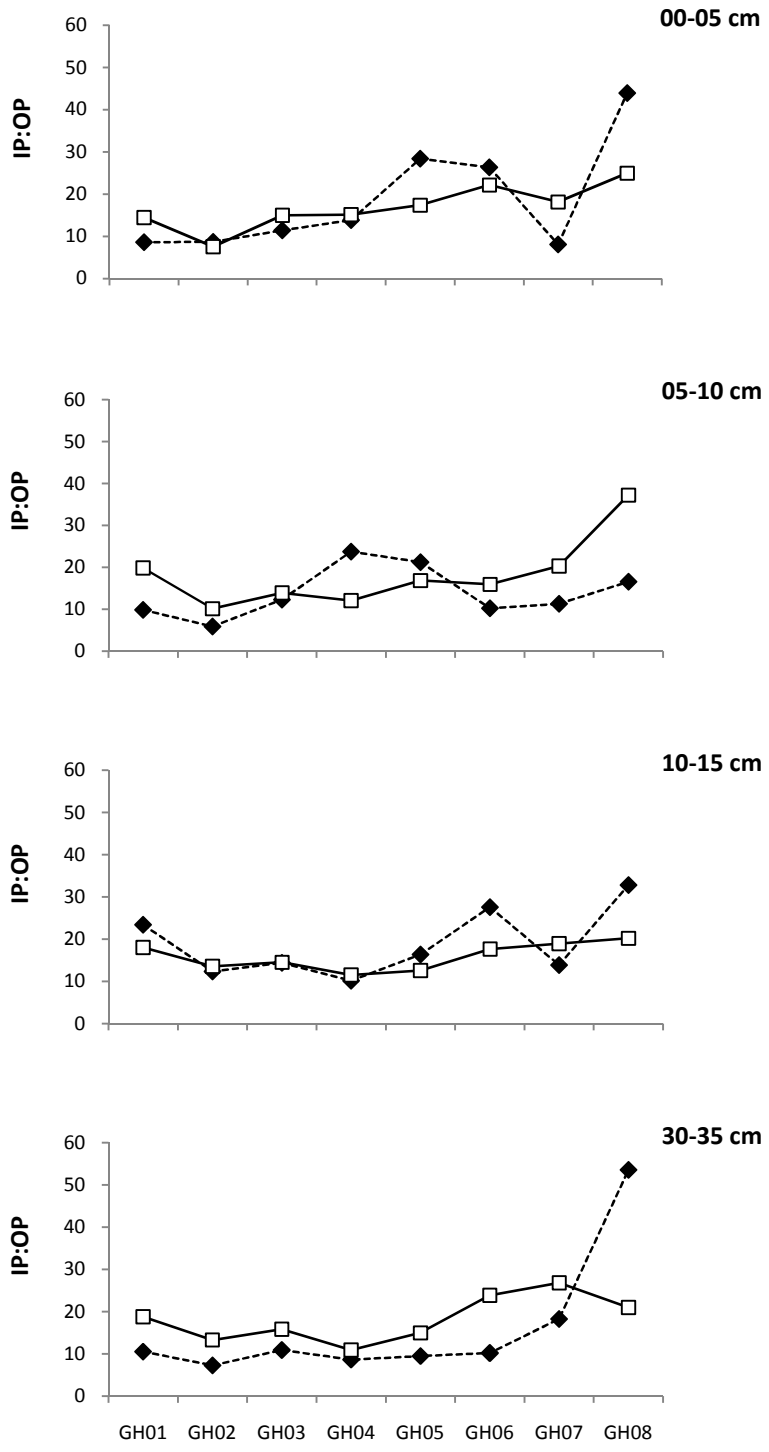


Figure 5.6: Variation of IP:OP ratio along the transect. ◆ dry, □ rainy season.

5.2 Chitin analysis

5.2.1 Method evaluation

Chitin is an important source of nitrogen in the coastal environments and originates from shells, diatoms, exoskeleton of zooplanktons, fecal pellets of crustaceans (Montgomery *et al*. 1990) and fungal cell wall (Mölleken *et al*. 2011, Nitschke *et al*. 2011). The quantification of chitin in surface water, sediment traps and sediments have been conducted by many authors (Jeuniaux *et al*. 1982, Poulicek and Jeuniaux 1982). Chitin can be determined indirectly through conversion to chitosan and quantified by colorimetric assay (Donald and Mirocha 1977, Mölleken *et al*. 2011, Nitschke *et al*. 2011). Subramanyam and Rao (1987) developed an enzymatic method to determine chitin in the fungal cell walls. In the samples containing mostly chitin besides minerals and proteins, chitin can be simply quantified through weighing as mentioned in Einbu (2007). Holan *et al*. (1980) determined chitin through the quantification of acetic acid liberated in the acidic or alkaline hydrolysis of chitin.

According to the applied method for this study, the first calibration point did not contain any chitin flake. Consequently, its fluorescence intensity was the highest. The decrease of fluorescence intensity with the increasing of chitin concentration, however, was not linear enough for calibration. The non-linear correlation between chitin concentration and fluorescent units can be attributed to the uncertainty in the actual amount of chitin in each standard, particularly at low concentrations. Consequently, the transfer of chitin stock solution to the vials as working standard solutions may be not correct as calculation although the stock solution was shaken well before pipetting. The fluorescent units of the calibration points which share a concentration gave the different values (table 4.4), confirms the error in the transferred chitin quantity. In addition, the height of vials used for this assay can be also a reason for the confusion in the fluorescent intensity of the calibration points as explained in the following. The sizes of chitin flake (Sigma, USA) are not homogenous. Shaking in narrow and high vials likely resulted in

the attachment of chitin flakes on the wall due to the high initial velocity of shaking. The loss of chitin from the suspension caused errors on the chitin concentration.

The measured fluorescence units of all sediments were higher than the first calibration point. This means there was another source of fluorescence in the sediments. Furthermore, the variability of the calibration values, especially the wide variation range of the blank after sixteen hours of incubation (table 4.4), may emphasize the influence of incubation time on the stability of FITC-WGA in the phosphate buffer.

All of the kinetics samples were subject to the same incubation conditions. The fluorescent values of duplicates were very different from each other when measured after the minute 15, 30 and 60 minutes, indicating that this period was not long enough for FITC-WGA to reach the stable state. The table 4.5 shows that the least minor variations of blank fluorescent units were reached within 180 and 240 minutes. The kinetics experiment of the fourth calibration points also expressed the stable values of the fluorescent units after 180 minutes and lasted until the minute 240 (table 4.6). This can be a base to assume that the period of 180 to 240 minutes is the necessary time for the FITC-WGA to bind to chitin. After 240 minutes, the increase in the fluorescence unit may indicate liberation of FITC-WGA from the complex chitin~WGA-FITC. Nevertheless, the fluorescence intensity of FITC-WGA released from that complex is obscured. This kinetics experiment again suggests that 240 minute can be the appropriate time for incubation of chitin in the phosphate buffer with 2 mL FITC-labeled WGA.

The stable fluorescent units observed after 180 and 240 minutes indicated sufficient incubation, even for the sediment samples. Within this time, the stability was not only shown for the binding between FITC-WGA and chitin, but also for the fluorescence of the sediment itself. It is therefore apparent that four hours is the best choice for the incubation of chitin/ sediment in 5 mL phosphate buffer with 2 mL FITC-labeled WGA.

This assay (10 mg dry sediment incubated in 5 mL phosphate buffer with 2 mL FITC-labeled WGA during 4 hours at 2062 rpm at room temperature) revealed chitin

contents in the sediments of 10.2 - 77.2 $mg.g^{-1}$. These chitin contents exceeded the OC and TN contents in the sediments and were much higher than those values derived from Gluam. Nevertheless, the contents of chitin~FITC-WGA significantly correlated with the amount of diatom frustules (Nguyen and Pham unpublished) (figure 5.7). This finding suggested that in spite of the overestimation, chitin quantified through the binding with FITC-labeled WGA could reflect the ecological relationship, as diatoms are also a source of chitin in the sediments (Durkin *et al*. 2009, Gooday 1990, Smucker and Dawson 1986).

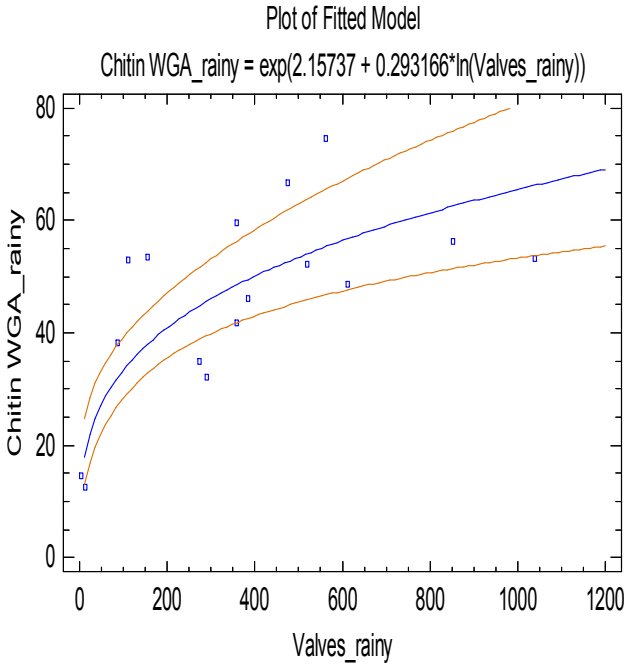


Figure 5.7: Correlation between the diatom frustules amount and chitin~FITC-WGA ($p = 0.0001$ and $r = 0.86$).

5.2.2 Chitin as a source of the sedimentary OM

Due to the overestimation of chitin quantified through the binding between Gluam and FITC-WGA, the chitin~Gluam contents were used for the calculation of the C_{chitin}:OC and N_{chitin}:TN ratio in the sediments (figure 4.50 and 4.51). Chitin~gluam contributed less than 2% of the total OC and less than 3% of the TN in the study area in the sampling year. Probably due to the entirely absence of the vegetation at the sand flat (GH08), the contribution of chitin~gluam to the pool of OC and TN at this site was significantly higher compared to the other sites, while there was no considerable difference in this ratio from GH01 to GH07 (figure 4.50 and 4.51).

As discussed above, the study area can be divided into the interior and exterior sector. Due to the low inundation frequency, the occurrence of planktons in the interior sector, namely GH01, GH02 and GH04, should be rare. Therefore, the contribution of marine planktons to chitin content in the interior sediment was negligible. However, the sedimentary chitin can derive from the sheath and fecal pellets of macrobenthos or diatom frustules (Montgomery *et al*. 1990). The concentration of chitin~WGA in the interior sediments decreased continuously from GH01 to GH04, corresponding with the decrease of burrow openings counted on the surface sediment, with an exception at GH03 where the number of burrow opening was higher than the other sites in the interior sector. (table 5.1). Thus, the concentration of chitin~WGA in the rarely inundated sites (GH01, GH02 and GH04) were likely derived from the fecal pellets of macrobenthos in the dry season. The high concentration of chitin at 30-35 cm at these sites probably resulted from the crustacean sheath at the bottom of the burrows.

The coincidence between the high number of burrow opening at GH03 (table 5.1) and the highest chitin~FITC concentration in the whole study area found in the depth of 30-35 cm (figure 4.19) showed that crustacean sheath was probably the major source of chitin in the deeper sediments. The concentration of chitin~FITC and chitin~Gluam in the surface sediments at GH03 were lower than GH01 and GH02 in the dry season (figure 5.11). These curves suggest that the sheath, as well as the fecal pellets of macrobenthos,

did not contribute remarkably to the surficial sedimentary chitin at GH03. The higher inundation at GH03 probably erased, or faded, the remnants of fecal pellets from macrobenthos.

In accordance with Nguyen (unpublished), the peaks of diatoms in the surface sediments were found at GH03 throughout the sampling year (figure 5.9). In addition, significant correlations between the concentration of chitin~Gluam, chitin~WGA and diatom frustules suggest that diatoms were a considerable source of chitin in this shallow creek (GH03). Nevertheless, as diatom chitin is fully acetylated, the calculation of chitin through the Gluam content may underestimate the total quantity of chitin in the sediment (McLachlan *et al*. 1965). Consequently, the peaks of chitin~Gluam contents did not coincide with the peaks of diatom frustules (figure 5.11).

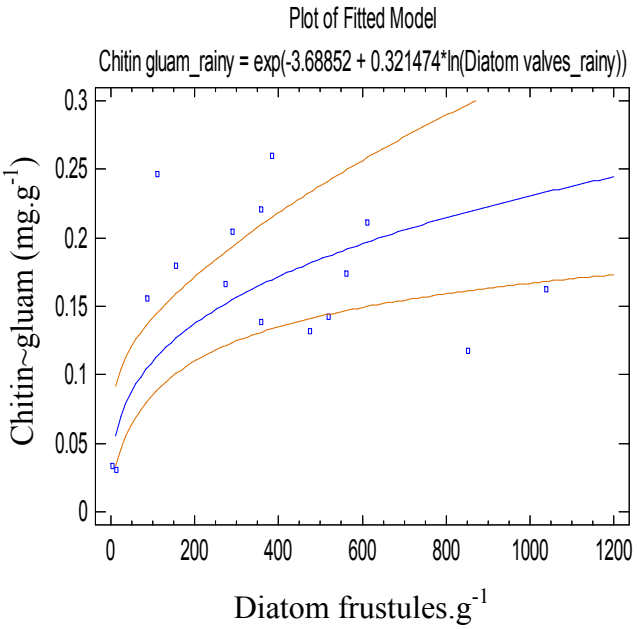


Figure 5.8: Correlation between the diatom frustules amount and chitin~Gluam in the rainy season ($p = 0.0006$ and $r = 0.76$).

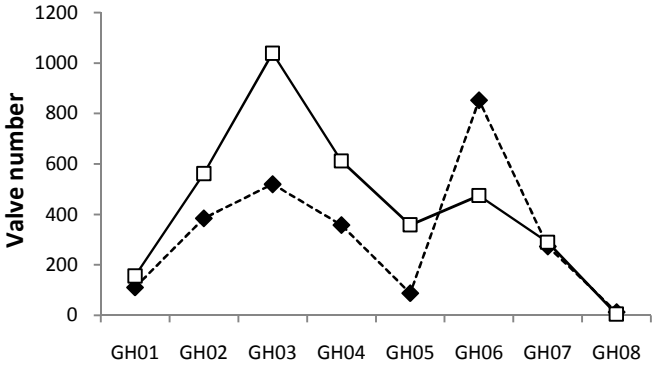


Figure 5.9: Variation of diatom frustules along the transect in the rainy season. ◆0-5 cm, and □ 05-10 cm. Data are kindly provided by Nguyen Thi Gia Hang.

In the upper sediments of exterior sector, the contents of chitin~gluam and chitin~FITC varied simultaneously with the OC and TN. The similarity in variation trends was more apparent in the dry season (figure 5.11). These findings may imply an important contribution of chitin to the OC and N pool. In the rainy season, the highest concentration of chitin~FITC was found at GH06 while the peak of chitin~Gluam was acquired at GH07 (figure 5.11). The peak of chitin~Gluam at GH07 coincided with the highest value of Gluam:Galam ratio (figure 5.10). This ratio is an indicator of the chitin-rich OM derived from zooplankton (Müller *et al.* 1986, Gupta and Kawahata 2000). In both seasons, zooplankton was probably the major contributor to the sedimentary chitin at GH07 while the peaks of chitin~WGA at GH06 coincided with the highest quantity of diatom frustules. These findings imply an important contribution of marine plankton and diatoms to the sedimentary chitin at the more-tidal-affected sampling sites.

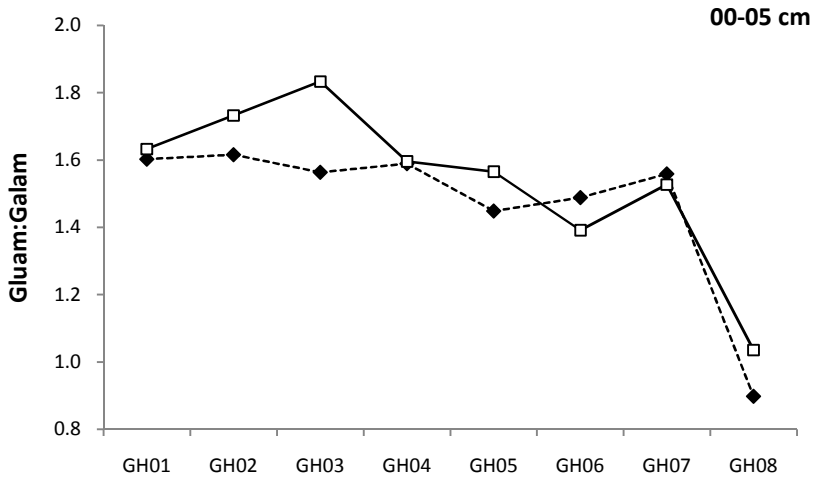


Figure 5.10: Variation of Gluam:Galam ratio in the surface sediments along the transect. ◆ dry, □ rainy season.

Table 5.1: Crab burrow opening counted in the sediment surface in the dry season. Data was kindly provided by Dr. Diele.

Site	Burrow opening (hole.m^{-2})
GH01	17
GH02	17
GH03	43
GH04	13
GH05	0
GH06	100
GH07	0
GH08	0

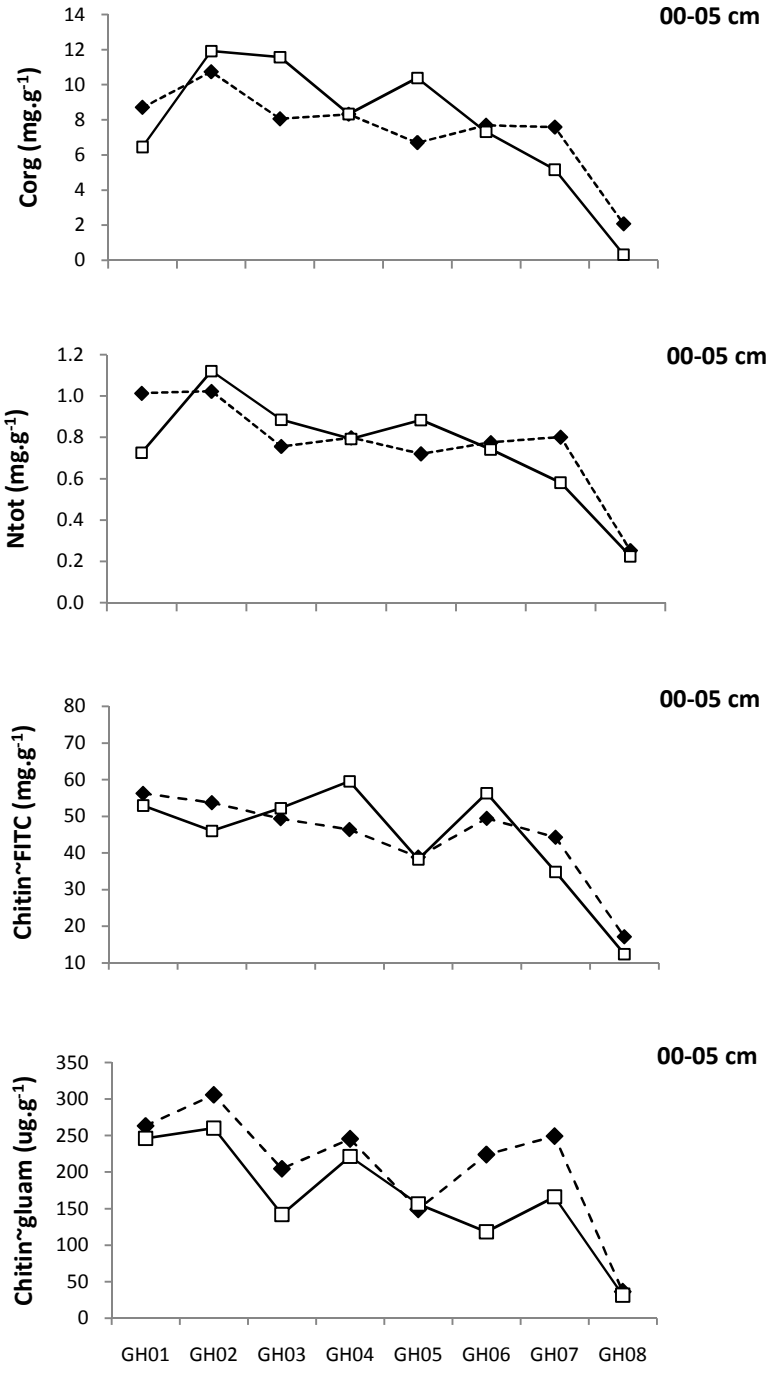


Figure 5.11: Variation of OC, TN, chitin~WGA and chitin~gluam in the surface sediments. ◆ dry, □ rainy season.

The chitinous OM derived from planktons also influenced the interior sector in the rainy season. Sea water could intrude the interior sector through the man-made shallow creek (GH03). Due to the effects of monsoon in the rainy season, a higher volume of water and particulates might enter the interior sector and the inundated area in this sector might be wider. The Gluam:Galam ratio at GH03 was higher in the rainy season compared to the dry season (figure 5.10) revealing the more predominant contribution of marine zooplankton to chitin pool at GH03 and GH02 in the rainy season. Furthermore, the abundance of *Vibrio* at GH02 and GH03 in the rainy season (Pham and Nguyen unpublished) probably resulted in the lower chitin in the sediment as they can effectively break down this biopolymer (Cottrell and Kirchman 2000, Riemann and Azam 2002, Suginta *et al.* 2004).

Chitin~gluam and chitin~FITC significantly increased with the increase in the proportion of the grains smaller than 63 μm (figure 5.12). The large contact area of these fine grains likely favored the attachment of diatoms on their surface, resulting in the high content of chitin in these sediments. This result may indicate that the dominant source of chitin in the interior sediments where the silt clay fraction dominated in the sediment structure was diatoms besides the fecal pellets and sheath of the macrobenthos. Moreover, figure 5.10 indicates a more planktonic OM at GH01, GH02 and GH04. The marine zooplanktons were probably introduced to these sites by the sea water when they were used for salt production. The similarity between both chitins and the total OC and TN in the exterior sector suggested that the contribution of vegetation to the pool of OC and TN in this area is negligible. This is also supported by the finding that the C:N ratio in the exterior sector was lower than the interior sector.

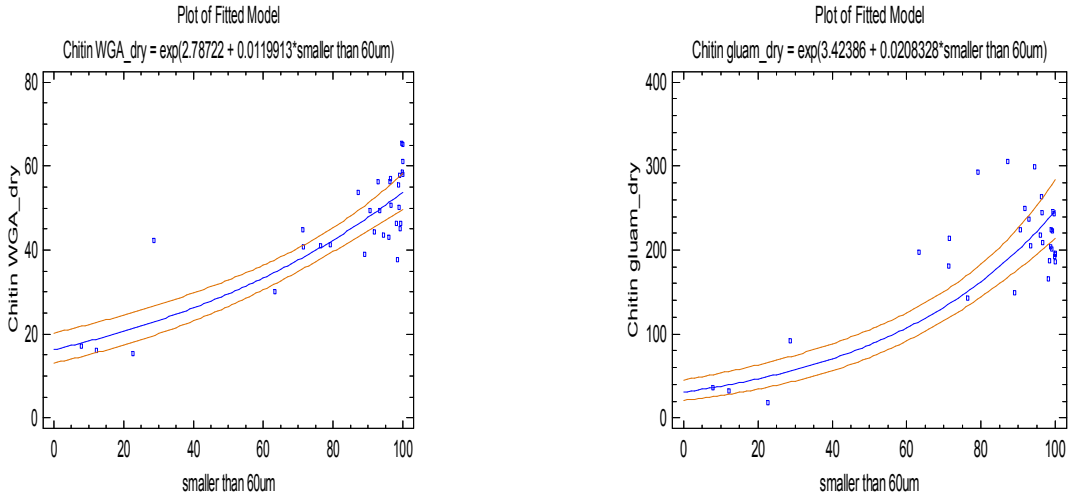


Figure 5.12: Correlation between the proportion of grains smaller than 63 μm and (a): chitin~FITC (p = 0.0001, r = 0.87); (b): chitin~gluam (p = 0.0001, r = 0.87).

Contrary to the expectance, the average values of chitin~Gluam and chitin~FITC in the exterior sector were lower as compared to the interior sector while the abundance of planktons in the exterior sector should be higher, due to the higher inundation frequency. The highest quantities of chitins were found at GH01 and GH02, where the burrow opening density was lower than the other sites, yet the fine grains were more dominant in the sediments. The difference in chitins between the interior and exterior sector may therefore be related to the grain size distribution in the sediments. The predominance of the fine grains (silt-clay fraction) associated with the harsher condition in the interior sector (*eg*. dry and saline) probably promotes the preservation of chitin. On the contrary, the high proportion of the coarse grains, along with the better sediment conditions, *e.g.* higher humidity and lower salinity, caused by the frequent tidal inundation probably accelerated the proliferation of the bacteria which in turn carry out the chitin degradation. Many bacteria are shown to degrade chitin in marine

environments (Soto-Gil 1988, Bassler *et al*. 1991, Montgomery and Kirchman 1993, Montgomery and Kirchmann 1994, Svitil *et al*. 1997, Park *et al*. 2000, Meibom *et al*. 2005, Pruzzo *et al*. 2008, Suresh 2012). These bacteria originate from sea water. Consequently, their demand of humidity is high. Their abundance in the exterior sediments probably accelerated the chitin degradation.

5.3 Characterization and composition pattern of amino acids

The constituent and composition pattern of amino acids in the study area were consistent through the sampling year, regardless of the dominant plant species and inundation frequency. Asp, Gly, Glu and Ala were the most abundant amino acids whereas Tau and Met were found only as traces (figure 4.29 and 4.30). Similar results were claimed by many authors (Stevenson 1956, Gupta and Reuszer 1967, Sowden 1968, Christensen and Bech-Andersen 1989, Campbell *et al*. 1991, Senwo and Tabatabai 1998, Friedel and Scheller 2002). Land use was thought not to affect the proportion of individual amino acids to THAAs (Huntjens 1972, Kowalenko 1978). However, these authors compared the soil of forests, grasslands, and agricultures. The stability in amino acids composition through depths in marine sediments was recorded by Henrichs (1987). Our results agreed with the available studies that soil/sediment conditions do not significantly influence the constituent and composition pattern of the individual amino acids.

The down-core variation of the THAAs was different from site to site and also different between the dry and rainy season (figure 4.20). In the dry season, the content of THAAs decreased with depth at GH01, GH02 and GH06, probably due to the consumption by microorganisms as a source of OC (Burdige and Martens 1988). The downward decrease of THAA concentration in sediments was recorded by many authors (Rittenberg *et al.* 1963, Degens *et al.* 1964, Brown *et al.* 1972, Boski *et al.* 1998, Andersson 2000, Grutters *et al.* 2002, Schmitt 2006). On the contrary, the down-core increase in THAA content was found at GH04 and GH05 probably due to the artificial disturbance in the past (soil digging at GH04 for plantation and building the saltpan wall

at GH05). However, the disturbance from building the saltpan wall was seen down-core to 10 cm which is the usual height of the saltpan walls. The contents of THAA in the surface sediments were similar at all sites with an exception at the saltpan wall (GH05), which was comparable to the THAA contents in 30-35 cm at the interior sites. These findings suggest that the so-called "surface sediment" at GH05 was actually deep sediments transported from other sites of the study area. Below this "surface sediment", the down-core variation of THAA contents followed the general trend. The continuous down-core increase at GH04 probably resulted from the digging for plantation. The sediments were dug and built up the mounds keeping the *Lumnitzera* saplings straight (Vu pers. comm.). The high THAA contents at GH02 were probably related to the THAA content in the dominant plant species. The mean content of THAA in *Avicennia* leaves in the dry season was 72 $mg.g^{-1}$, while it was 28 and 46 $mg.g^{-1}$ in *Sesuvium* leaves and *Lumnitzera* leaves, respectively. The highest THAA concentration in the surface sediment at GH02 probably resulted from the high biomass of plants (Vu pers. comm.). Litter from vascular plants is a major source of amino acid in mangroves and hypersaline sediments (Woodroffe 1985).

The highest concentration of THAA in the sediments was 3.12 $mg.g^{-1}$. This is lower than the quantity of THAA recorded in Brazil by Jennerjahn and Ittekkot (1997) and Schmitt (2006). The THAA concentration in a mangrove located in the East of Brazil was 14.3 $mg.g^{-1}$ (Jennerjahn and Ittekkot 1997). In the North of Brazil, the THAA concentration varied between 2.08 and 11.16 $mg.g^{-1}$ (Schmitt 2006). The difference in THAA concentration between the studied mangrove and other regions were probably related to the content of sedimentary OC and N due to the different vegetation densities. The extremely low values of OC and TN contents in Ganh Hao occurred at the sand flat where the coarse sand predominated in the grain size distribution. In the mangrove in the East of Brazil, the OC and TN accounted for 4.82 % and 0.42 % of the dry weight sediment (Jennerjahn and Ittekkot 1997). The OC content in Indian mangroves varied from 17.68 to 53.57 $mg.g^{-1}$ (Ravi 2005).

Before the plantation in 1998, the interior sector of the study area was used for salt production. During that period, these sediments received mostly marine OM input, *e.g.* planktons which enter the sediments via tidal water. After the mangrove plantation in 1998, due to the sparse vegetation and the high rate of evaporation (higher than 1000 $mm.year^{-1}$), there are many cracks on the surface sediments. Consequently, the sediments were more aerated due to the intrusion of air or well-oxygenated water. Thus, the turnover rate of OM was probably higher (Twilley *et al.* 1992, Reghunath and Murthy 1996, Bridgham *et al.* 1998, Lallier-Verges *et al.* 1998), resulting in the low accumulation of OM in this sector.

The level of sedimentary OC and TN in the study area was lower than another mangrove that was also replanted in abandoned salt-pan. In a mangrove of *Ceriops* and *Rhizophora* replanted in an abandoned salt-pan in Can Gio, Ho Chi Minh City, the sedimentary OC varied from 0.80 to 5.16 % in the dry season and 0.68 to 5.41 % in the rainy season (Tran 2007). This is probably related to the quality of the OM input. The dominant species in Can Gio are *Rhizphora* and *Ceriops*. Due to the high content of tannin in the leaves of Rhizophoraceae species, the C:N ratio in these leaves is high. The C:N ratio in the *Rhizophora* leaf litter was *ca.* 60 (Pham 2007) while in Ganh Hao, the C:N ratio of *Avicennia* and *Lumnitzera* was 22 and 44, respectively. The C:N ratio in plant material is an indicator of the mineralization rate of the tissue in the sediments. The OM with high C:N ratio are more resistant to degradation (Miller 2000, Khalil *et al.* 2005) resulting in the high content of OM in the sediments.

According to Meyers (1994) and Prahl *et al.* (1994), the sedimentary C:N ratios higher than 20 reflects the contribution of terrestrial plants to the pool of OM. The values of C:N ratio in marine plankton and algae are less than 10 (Jenkinson and Ladd 1981, Emerson and Hedges 1988, Dehairs *et al.* 2000, Marchand *et al.* 2003). The sedimentary C:N ratio in Ganh Hao did not exceed 18. This value suggested that the sediments received OM from both marine plankton and terrestrial plants. In the rainy season, the increase of C:N ratio in the surface sediment at GH03 and GH05 (figure 5.13) relative to

the dry season probably reflected an increase in the contribution of mangrove plants to the pool of sedimentary OM (Guilizzoni *et al.* 1996). Because the sites GH03 and GH05 were topographically lower than GH01, GH02 and GH04 (figure 2.2), these two sites probably received the OM washed from the higher sites by the rainfall. The down-core decrease of C:N ratio at the interior sites (figure 5.14) shows that prior to the mangrove plantation, the marine plankton entering the interior site via sea water for salt production was the major source of sedimentary pool of OM.

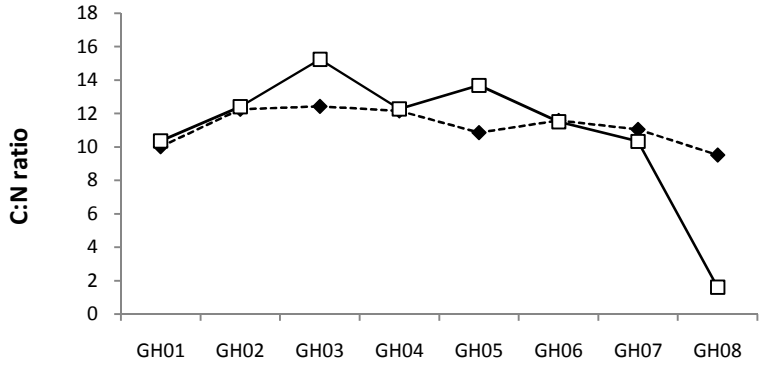


Figure 5.13: Fluctuation of C:N ratio in the surface sediment. ◆ dry, □ rainy season.

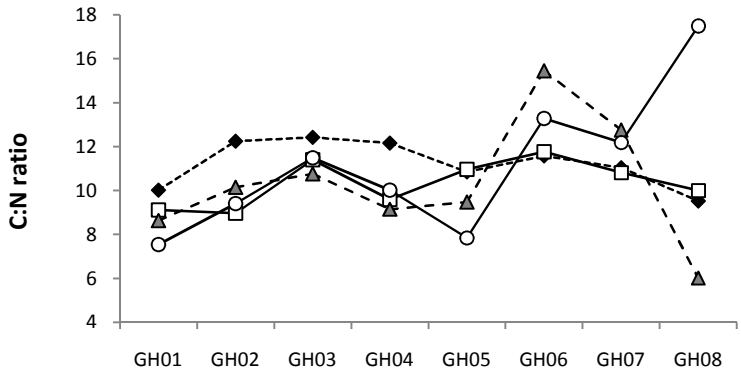


Figure 5.14: Down-core variation of sedimentary C:N ratio along the transect in the dry season. ◆ 0-5 cm, □ 5-10 cm, ▲ 10-15 cm, ○ 30-35 cm.

The THAAs accounted for *ca*. 26% of the TN pool in the sediments in Ganh Hao. This is lower than the finding of Jennerjahn and Ittekkot (1997) in Brazilian mangroves. However, our results are in agreement with Friedel and Scheller (2002) in an arable land. The mean contribution of C_{aa} to OC pool in the sediment was *ca*. 9 and 11% in the dry and rainy season, respectively. This finding agreed with the contribution of amino acids to the sedimentary OC pool in Bengal Bay (Unger *et al.* 2005). The significantly higher ($p < 0.01$) C_{aa}:OC ratio in the rainy season, as compared to the N_{aa}:TN ratio suggested that organic nitrogen was preferentially consumed in the rainy season. The C:N ratio in Ganh Hao was less than 18 and thus, it is advantageous to nitrogen mobilization (Boto 1982). The slight increase of N_{aa}:TN ratio in the rainy season probably reflected a preference in nitrogen mineralization as compared to OC.

In general, the N_{aa}:TN and C_{aa}:OC ratio decreased slightly down-core with an exception at the disturbed sites (GH04 and GH05) (figure 4.22 and 4.23). The decrease of C_{aa}:OC and N_{aa}:TN ratio suggested that the amino acids were consumed within 0-15 cm. The consumption could be faster at some sites such as GH02 and GH04 but the consumption rate was probably lower in the depth of 30-35 cm. The amino acids were likely preserved under aerobic condition. Burdige and Martens (1988) also found the slightly down-core decrease in C_{aa}:OC and N_{aa}:TN ratio.

The acidic amino acids are usually more abundant in the tropical soils (Friedel and Scheller 2002). The finding that acidic amino acids were more abundant than basic amino acids in Ganh Hao agreed with the finding of Ravi (2005) in two mangroves in India. The acidic amino acids mostly originate from the terrestrial plants (Akiyama and Johns 1972, Kemp and Mudrochova 1973) and, hence, their contents and composition pattern were higher at the site occupied by vascular plants in Ganh Hao (table 4.8). The acidic amino acids were probably preserved in the deeper layers of the sediments, especially in the rainy season (table 4.8).

In the dry season, the content of acidic and basic amino acids tended to increase with depth at most of the sites, with an exception at GH04. The dwarf *Lumnitzera* forest

was replanted in 1998 and the soil was dug to build mounds to keep the saplings straight (Vu pers. comm.). Consequently, the sediments in this replanted forest were subject to a disturbance and result in the reverse tendency of the down-core variation in the quantity of the acidic, as well as the basic amino acids. Contrary to the acidic amino acids, the basic amino acids increased towards the sea. The basic amino acids are more stable in depositional environments (Gonzalez *et al*. 1983), or increase during degradation in sediments of continental slopes over a large time scale Steinberg *et al.* (1987).

Neutral and acidic amino acids were the most dominant groups in the sediments of Ganh Hao (figure 4.24). Neutral amino acids contributed *ca*. 53% to the THAAs. This is the most abundant group of amino acids in Ganh Hao, similar to the available studies conducted in the coastal and deltaic environments (Gonzalez *et al.* 1983, Burdige and Martens 1988). There is a similar contribution of acidic amino acids to the THAA in mangrove sediments. Acidic amino acids accounted for 25.94 ± 0.44 mole % and 24.95 ± 0.44 mole % of the THAA in the dry and rainy season, respectively. In a mangrove in the eastern of Brazil, the mole % value of acidic amino acid was 24.4 ± 1.2 (Jennerjahn and Ittekkot 1997). However, the more abundance of non-protein amino acid in the study area (3.66 ± 0.26 mole % in the dry season and 3.77 ± 0.32 mole % in the rainy season) in comparison with that Brazilian mangrove (2.3 ± 0.3 mole %) (Jennerjahn and Ittekkot 1997) indicated that the diagenesis state of OM in Ganh Hao was probably higher. The increase of non-protein amino acids (β-Ala and γ-Aba) with the degradation of OM has been shown by many authors in different environments (Casagrande 1974, Schroeder 1975, Whelan 1977, Given 1980, Lee and Cronin 1982, Hatcher *et al.* 1983, Henrichs and Farrington 1984, Cowie and Hedges 1992, Cowie and Hedges 1994, Casagrande and Keil *et al.* 2000, Xing *et al.* 2007).

Although no apparent trend of variation through landscapes was seen in the neutral amino acids, their mean values showed that they were more abundant at the sites affected by the tidal water and no vegetation, including GH03, GH07 and GH08. Thr, Ser, Gly are the dominant amino acids in diatom cell walls and marine planktons (Siezen and Magne

1978). In accordance with Nguyen (unpublished), the diatom frustule number was highest at GH03 in the rainy season (figure 5.9). The abundance of diatom at GH03 probably resulted from the tidal influence and high proportion of fine grains in the sediments. Due to the abundance of the coarse grains at GH07 and GH08, together with the sweeping of tidal water, the diatoms were probably washed up while they accumulated in the creek (GH03), resulting in the more abundance of Thr and Ser - the major components in diatom cell walls and hence, the more abundance of neutral amino acids at GH03. However, diatoms cannot account for the abundance of the neutral amino acids at the mud and sand flat. Marine planktons probably were the major contributors to the relative abundance of the neutral amino acids at these sites, due to the richness of Thr, Gly and Ser in their biomass (Siezen and Magne 1978).

Aromatic amino acids, inclusive of Phe and Tyr, were more abundant at the sites which were more affected by the tides, namely at GH03, GH06, GH07 and GH08. Similar to a study in deltaic sediment conducted by Gonzalez *et al.* (1983), Phe was more abundant than Tyr in Ganh Hao (more than 64% of the total abundance of Tyr and Phe). Phe was claimed to be more abundant in the marine sediments (Gonzalez *et al.* 1983).

In the dry season, Met was found in the surface sediments at the dry and saline sites and seemed to be more abundant at the sites frequently affected by the tides. The total sulfur-containing amino acids were higher in the rainy season and they were the most abundant at the sand flat. According to Gonzalez *et al.* (1983), the sulfur-containing amino acids were absent in the aerobic marine sediments. In our hypersaline area, due to the high proportion of coarse sand at the sand flat, the redox-potential was positive down-core to 15 cm. The reason for the higher mole fraction of sulfur-containing amino acids in the sand flat is, therefore, uncertain and cannot be explained by the present data.

Non-protein amino acids were less abundant at the sites which were more affected by the tidal waters (GH06, GH07 and GH08). In general, their mole fraction tended to increase from the dry and saline sites towards the wet and non-vegetated sites. Salinity may affect the abundance of non-protein amino acid in sediments, as γ-Aba was shown to

accumulate under salt stress from the polyamine degradation (Xing *et al.* 2007). The abundance of β-Ala and γ-Aba at GH01, GH02, GH04 and GH05 were possibly resulted from the degradation of plant materials. The low mole fraction at the frequently flooded sites GH03, GH07 and GH08 corresponded with the absence of OM derived from plants, or due to the tidal export of the OM.

In the upper sediments (within 0-15 cm), the reactivity index (RI), the Asp:β-Ala and Glu:γ-Aba ratio tended to increase from the dry and saline sites towards the sea (figure 5.15, 5.16 and 5.17). The RI is used as an indicator for the degradation state of the OM and calculated by the ratio of aromatic amino acids to non-protein amino acid (Alkhatib *et al.* 2012). The highest values of RI and these ratios was found in the surface sediment at GH02 indicating a comparatively weak degradation or a fresh input of OM. *Avicennia* was the dominant species at GH02 and this plant can remove the leaves based on the salt concentration in their vacuoles, independent of the senescence of the leaves. Thus, the OM input at GH02 was probably more frequent, particularly in the dry season. The sudden increase in these values at GH02 was seen only in the top sediment (0-5 cm). Within 5-15 cm, the RI, the Asp:β-Ala and Glu:γ-Aba ratio increased from GH01 to GH03 and from GH04 to GH08, indicating an OM renewal in the sites affected by the tides.

Our data confirmed the finding of Alkhatib *et al*. (2012) that the mole fraction of β-Ala and γ-Aba increased significantly down-core, indicating a more degradation state of OM in the deeper layer of the sediments. Nevertheless, there was an exception at GH06, where the Asp:β-Ala and Glu:γ-Aba ratio increased down-core within 0-15 cm (figure 5.16a and 5.17a). This can be attributed to the biodisturbance caused by the dwelling organisms which can be seen in the down-core variation of OC and TN. The similar variation trends were found in the rainy season. However, the biodisturbance seemed to increase in the rainy season, as indicated by the increase in the Asp:β-Ala ratio and Glu:γ-Aba ratio within 0-15 cm. This can be attributed to the behavior of the fiddler crabs living in the sand flat. In the depth of 30-35 cm, there was a similar variation in the

Asp:β-Ala and Glu:γ-Aba ratio along the transect between the dry and rainy season. Our study agreed with Hedges and Keil (1995) that the interior sediments which were more dominated by the terrestrial plants were less reactive or more refractory as compared to the outer sediments which were probably more dominated by the marine-derived OM.

The down-core variation of the Asp:β-Ala ratio and Glu:γ-Aba ratio at GH07 suggested a comparatively strong biodisturbance within 0 and 15 cm, with the higher ratios in the deeper sediments, indicating a preferential preservation of Asp and Glu in the deeper sediments. The C_{aa}:OC ratio at GH07 in 30-35 cm (figure 4.23) also indicated fresher OM in the rainy season. Due to the high proportion of the coarse grains in this depth at GH07, the OC content of this sample was lower than the other sites in the same depth (figure 4.11). Meanwhile, the highest C_{aa}:OC ratio was found in this depth. The low organic content at this depth resulted in the weak degradation and hence, the inorganic nutrient content, *e.g.* NH_4^+ and AP, ought to have been limited here. However, the contents of these nutrients were high at this depth (figure 4.8 and 4.9). This can be attributed to the root exudation of *Avicennia*, which contains organic acids, amino acids and amino sugars, to enhance the nutrient acquisition (Dakora and Phillips 2002).

The C:N ratio at GH07 decreased from 12 in the dry season to 9.8 in the rainy season, suggesting a bacterial source of OM (Jenkinson and Ladd 1981). At GH07, the high percentage of fine grains within 0 and 15 cm probably resulted in the strong reduction at 30-35 cm and hence, the anaerobic bacteria proliferation was promoted. The Gluam:Galam ratio varied between 0.89 and 1.82 indicated a strong degradation in the whole study area or a bacterial source of OM (Liebezeit 1993, Ogawa *et al*. 2001, Benner and Kaiser 2003).

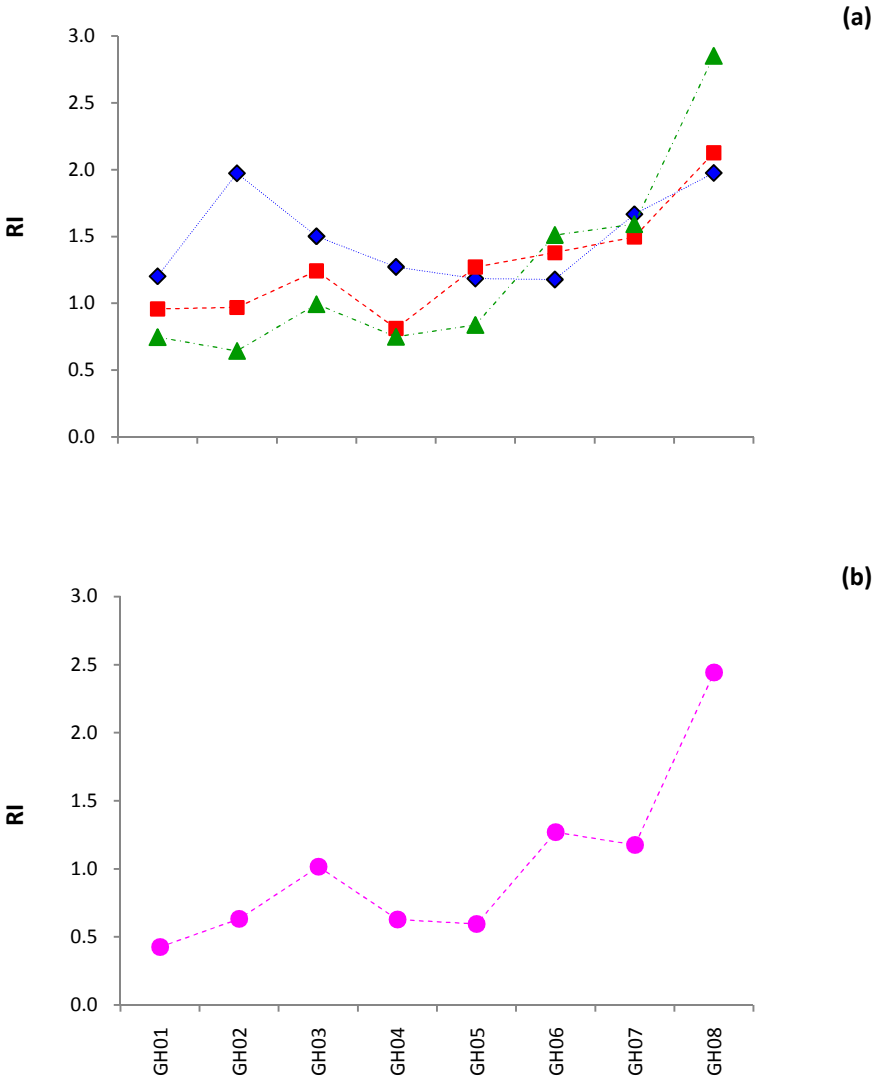


Figure 5.15: The seaward increase of RI in the dry season along the transect in (a): within 0 and 15 cm and (b): 30-35 cm. In (a), ◆ 00-05 cm, ■ 05-10 cm, and ▲ 10-15 cm.

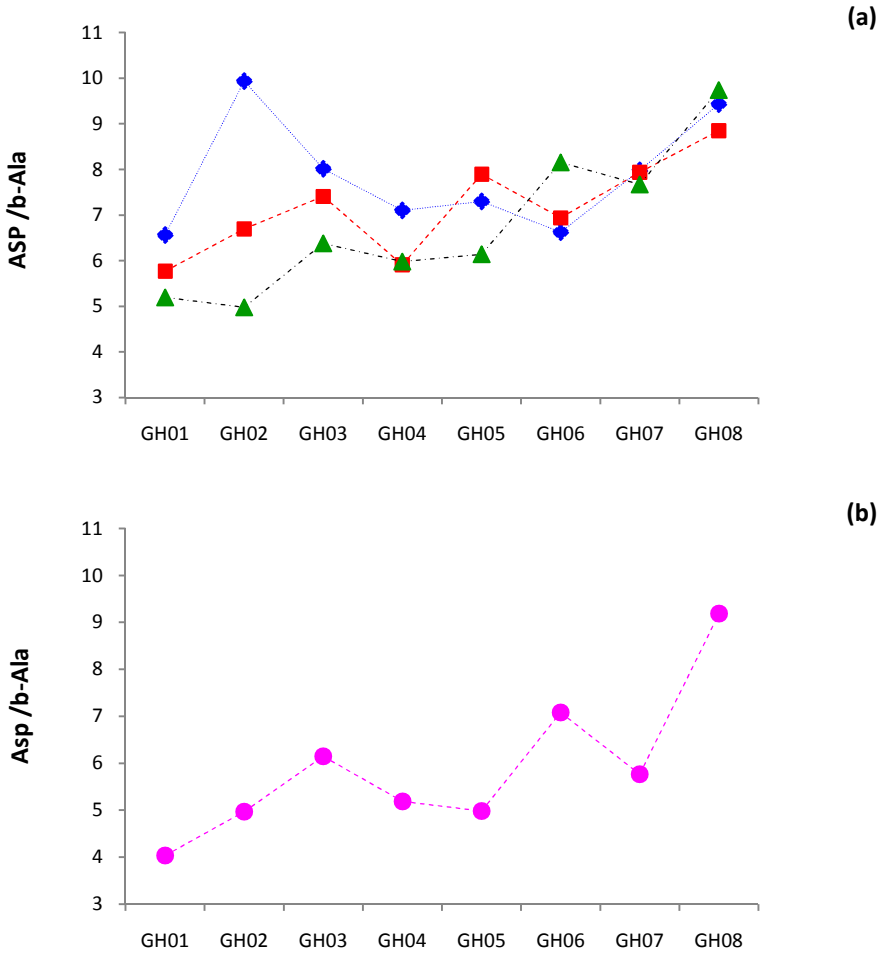


Figure 5.16: The seaward increase of Asp:β-Ala in the dry season along the transect in (a): within 0-15 cm and (b): 30-35 cm. In (a), ◆ 00-05 cm, ■ 05-10 cm and ▲ 10-15 cm.

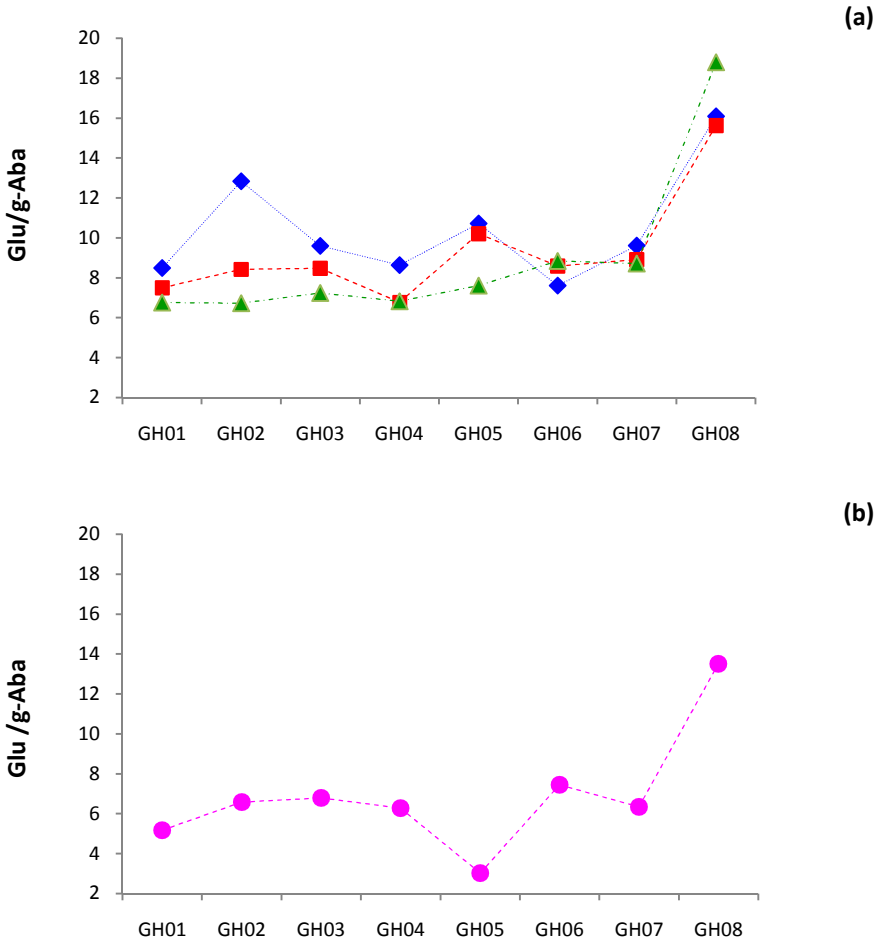


Figure 5.17: The seaward increase of Glu:γ-Aba in the dry season along the transect in (a): within 0-15 cm and (b): 30-35 cm. In (a), ◆ 00-05 cm, ■ 05-10 cm and ▲ 10-15 cm.

Gly accumulated during the degradation process (Lee and Cronin 1984) as it is the major component in diatom cell wall and bacteria to form the protein-silica complex (Muller *et al.* 1986, Ingalls *et al.* 2003), a kind of refractory OM in the sediments (Siezen and Magne 1978, Lee *et al.* 2000). Moreover, its nutritional value for the organisms in sediments is low (Dauwe and Middelburg 1998). Therefore, it should tend to increase with depth (Haugen and Lichtentaler 1991, Cowie *et al*. 1992). In the study area, the mole fraction of Gly increased from 0 to 15 cm at GH01, GH02, GH03, GH04, GH06 and GH07 in the dry season, indicated that Gly was preserved in the sediments. Nevertheless, at GH02, GH03, GH06, GH07 and GH08 in the rainy season, the continuous decrease in Gly mole fraction referred to a preferential loss of this amino acid, but it was negligible. This finding shows that there could be another fate for Gly in the sediments which are subjected to the alternation of exposed and flooded.

In addition to Gly, the hydroxy amino acids (Ser and Thr) are also predominant in the diatom cell wall (Siezen and Magen 1978, Lee and Cronin 1984, Müller *et al.* 1986). They are resistant to the degradation due to their reaction with phenolic compounds to form humic complex (Degens 1970, Siezen and Magne 1978). Consequently, their mole fractions were expected to increase with depth, as they are preferentially preserved during the degradation process. However, similar to Gly, the down-core decrease of Ser and Thr exhibited a loss of these amino acids. These findings are contrary to the literature. Nevertheless, at GH01, GH02 and GH04 in the dry season, the mole fraction of Ser and Thr decreased down-core, similar to the study of Alkhatib *et al*. (2012). However, in the rainy season, the negligible variation of Ser and Thr within 5-10 cm suggested that they were preferentially preserved in this depth. The trend of variation related with depth disappeared in the sediments at GH05 and GH08. The similar results were reported in the study of Alkhatib *et al*. (2012) and they attributed it to the increasing contribution of bacterial necromass to the bulk sediments OM with ongoing degradation (Keil *et al*. 2000). In Ganh Hao, the mole fraction of Ser was higher than Thr during the sampling

year ($p > 0.05$), suggesting a more marine source of OM in the sediments (Gonzalez *et al*. 1983).

According to Gonzalez *et al.* (1983), Val, Leu and Ile are less stable and thus, they are probably easy to be degraded or consumed. Furthermore, they are essential amino acids. Thus, their mole fraction down-core decline in the hypersaline sediments probably resulted from the preferential consumption by sediment microorganisms (Burdige and Martens 1988) or preferential degradation in the aerobic layers of the sediments. The down-core decrease in mole fraction of Val, Ile and Leu agreed with the finding of Gonzalez *et al*. (1983) that these branched chain amino acids are easy to be degraded.

The down-core decrease of Ala mole % at the sites from GH02 to GH04 and from GH06 to GH07 indicated a preferential loss in the sediments from the surface to the depth of 30-35 cm. Nevertheless, the mole fraction of Ala increased in the depth of 5-10 cm in the rainy season indicating a preservation of Ala in this depth. Meanwhile, in the sediments at GH05 and GH08, Ala seemed to be preferentially preserved in the deeper sediments. However, the sediments at GH05 and GH08 were probably subject to bioturbation caused by the dwelling animals, resulting in the vague relationship between depth and the trend of amino acid mineralization.

Of the acidic amino acids, the mole fraction of Asp was significantly higher than the mole fraction of Glu ($p < 0.001$), indicating that most of the study area received the OM derived from terrestrial plants (Khan and Sowden 1972, Pelet and Debyser 1977). Within 0-15 cm, the Asp:Glu ratio was *ca*. 1.3 and increased towards the tidal affected sites in the dry as well as the rainy season. This finding indicated an accumulation of OM derived from terrestrial plants or the plant-derived OM was transported from the interior sector to the sea. There was a sudden high of Asp:Glu at GH05 in the dry season, corresponding with the high value of pH at this site at 30-35 cm. This coincidence can be attributed to the affinity bonds between the acidic amino acids and carbonate grains (Carter and Mitterer 1978, Ittekkot *et al*. 1984, Wakeham *et al*. 1993, de Lange *et al*. 1994, Cowie *et al*. 1995).

The mole fraction of Tyr and Phe decreased down-core at most of the sampling sites indicating that these amino acids were preferentially lost during the decomposition progress (Dauwe and Middelburg 1998) as these are the dominant amino acids in the cytoplasm. The down-core decrease of Phe, Ile and Leu indicated that the degradation state was stronger in the deep sediments or the OM in the deep sediments was more refractory.

Arg tended to decrease down-core at most of the sampling sites, regardless of the occurrence of vegetation. Arg is mineralized to NH_4^+ and its ammonification rate was proportional to the soil microbial biomass (Alef and Kleiner 1987). The down-core decrease of Arg suggested a strong ammonification in the deep sediments. The positive relationship between Arg and NH_4^+ content (figure 5.18) was highly significant in the dry season ($p < 0.001$). However, the correlation became less pronounced in the rainy season ($p < 0.01$).

Arg, His and Met are the essential amino acids. Therefore, they are preferentially consumed by the microorganisms in the soils/sediments, resulting in the down-core decrease of their mole fraction. Met was the most consumed amino acid as it particularly disappeared under 10 cm in the dry and vegetated sites. The down-core decrease of His was very negligible.

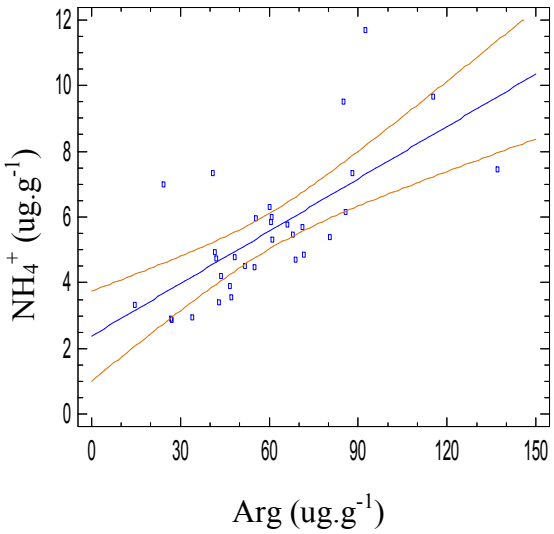


Figure 5.18: Correlation between Arg and NH_4^+ content in the dry season. The p-value and correlation coefficient was 0.0001 and 0.69, respectively

At GH01, GH02 and GH04, the sediments were characterized by the high salinity and low humidity in the dry season. The down-core increase in the mole fraction of Asp and Glu throughout the sampling year indicated a preferentially microbial utilization in the upper layers (figure 4.39 and 4.40). Meanwhile, the mole fraction of β-Ala and γ-Aba also increased down-core (figure 4.48 and 4.49), contrary to the finding of other authors (Casagrande 1974, Schroeder 1975, Whelan 1977, Casagrande and Given 1980, Lee and Cronin 1982, Hatcher *et al.* 1983, Henrichs and Farrington 1984, Cowie and Hedges 1992, Cowie and Hedges 1994, Keil *et al.* 2000, Xing *et al.* 2007). Their increase indicated a higher degradation state and it usually results from the degradation of Asp and Glu. Nevertheless, β-Ala and γ-Aba can be also formed by other processes rather than the carboxyl reduction of Asp and Glu (Cowie and Hedges 1994). The sediments at GH01, GH02 and GH04 were very aerated in the dry season due to the low humidity which in turn resulted in the fractures in the sediments. Consequently, the P content may be a limiting factor for the plant growth. Thus, in order to enhance the nutrient acquisition,

plants probably promoted the root exudation to attract the microbial colonization. This finding is advocated by the highest AP:IP ratio in the depth of 30-35 cm and the high content of AP at the dwarf forest of *Lumnitzera racemosa* (figure 4.15).

At GH03, GH06 and GH07, the mole fraction of Asp increased continuously down-core in the dry season while it was lost at 30-35 cm in the rainy season (figure 4.39 and 4.40). The mole fraction of β-Ala consistently increased down-core in both seasons (figure 4.48 and 4.49). The mole fraction of Glu did not change within 0 and 15 cm but significantly decreased in 30-35 cm in the rainy season (figure 4.40). The mole fraction of γ-Aba consistently increased down-core indicating the higher state of OM degradation in these sediments (figure 4.48 and 4.49). The sediments in this group were disturbed by the crabs together with the tidal effects. The down-core increase of Asp and Glu probably resulted from the downward transportation of plant debris which was carried out by the macro invertebrates. The predominance of Asp relative to Glu indicated the terrestrial plant-derived of the sedimentary OM. The Glu is an indicator of planktonic source of the sedimentary OM. Consequently, the consistence of Glu mole fraction probably reflected the biodisturbance influence on the planktonic sedimentary OM. The low mole fraction of Glu in 30-35 cm indicated a limitation of planktonic OM input, probably due to the fine grains in the upper layers.

The sediments at GH05 and GH08 were characterized by the high pH and the predominance of the coarse grains resulting from the carbonate break down. The down-core decrease of Asp mole fraction in these sediments within 0-15 cm probably reflected the limited influence of plants at these sites. GH08 was totally non-vegetated and GH05 was subject to drastic erosion. The down-core decrease of Asp in these sediments can be attributed to the consumption of microorganisms. On the contrary, the mole fraction of Glu increased from 0 to 15 cm, probably due to the contribution of OM from marine planktons. GH05 and GH08 were predominated by the marine planktons while most of the sedimentary OM in the other sites originated from the terrestrial plants.

The down-core increase in Lys mole % in the sediments at GH01, GH02 and GH04 within 0 and 35 cm indicated a preferentially preservation of this amino acid in the dry and rainy season. Lys is enriched in vascular plants OM (Cowie and Hedges 1992). Consequently, it is more refractory and tends to be accumulated during the degradation. Nevertheless, no apparent trend was found in the sediments at the other sites. The sediments in these sites were subject to physical and biological disturbance by tides and macro invertebrates. The down-core variation, therefore, may be a faulty tool for the OM degradation assessment.

The preferential loss of Ile, Leu, Tyr and Phe in the sediments during early diagenesis was claimed by many authors and they were attributed to the high nutritional value for bacteria (Burdige and Martens 1988, Dauwe *et al.* 1999, Lee *et al.* 2000). Alkhatib *et al*. (2012) found an increase of OM degradation state towards the open waters through the lower concentration of these amino acids downstream relative to their concentration upstream. In Ganh Hao, in the sediments at GH01, GH02 and GH04, the down-core decrease in mole % of Ile, Leu and Phe in the dry and rainy season and the drastic decrease of Tyr within 0-10 cm suggested a preferential consumption by the sediments organisms living in the sub-surface sediments. These results indicated an increase in OM degradation state in the deep sediments at GH01, GH02 and GH04.

At GH03, GH06 and GH07, the down-core decrease in the mole fraction of Ile, Leu and Phe were acquired in the dry season exclusively. This finding indicated the preferential consumption of these amino acids by sediment bacteria for these amino acids cannot be synthesized by organisms. In the rainy season, their mole fraction did not show any consistent tendency of variation probably due to the biodisturbance caused by the dwelling animals. There was no tendency of down-core variation in Tyr mole fraction in both seasons, but in the rainy season, a drastic increase in Tyr in the depth of 30-35 cm indicated an accumulation or a supplement of Tyr in the sediments.

At GH05 and GH08, the mole fraction of Ile, Leu, and Phe in 30-35 cm were higher compared to the sediment in the dry season. However, in the rainy season, the

mole fraction of Ile, Leu and Tyr showed a preferentially loss and hence, indicated an increase in OM degradation while no variation trend was found in Tyr contents. At the other sites, the mole fraction of Val increased down-core in the dry season. There was a drastic loss of Val in the sediments within 0 and 15 cm at GH01, GH02 and GH04 while it was negligible at GH03, GH06 and GH07. The significant loss of Val at GH03, GH06 and GH07 occurred exclusively in the depth of 30-35 cm in the dry season. The down-core variation trend at these three sutes was similar to the dry and saline sediments in the study area (GH01, GH02 and GH04) but more linear and found only in the rainy season. These findings suggested a preferential loss of Val in the dry season.

Dauwe and Middelburg (1998) claimed that the concentration of the essential amino acids did not increase with the increase of N_{aa} contents in a bioturbated sediment. In the dry season, the mole fraction of Arg and Met exhibited a down-core decrease in the dry and rainy season. These amino acids are deficient even in the source organisms (Dauwe and Middelburg 1998). Our data also agreed with their finding as Met was found as traces only in the sediments. Consequently, they are usually taken up by the sediment organisms for their nutritional requirements (Phillips 1984). On the contrary, His content showed a down-core increase between 0 and 15 cm and significantly decreased in 30-35 cm. Based on these findings, the degradation state of the OM tended to increase in the deep sediments.

The mole fraction of Orn consistently increased down-core, inversely proportional to the down-core variation of Arg. Orn is the product of Arg degradation and this non-protein amino acid was found to accumulate during the degradation of sedimentary OM (Funck *et al.* 2008).

In general, the down-core variation of the individual amino acids at the dry and saline sediments (GH01, GH02 and GH04) where the biodisturbance was negligible, was similar to the published results. However, the sediments at the sites with low carbonate content (GH01, GH02, GH03, GH04, GH06 and GH07) were subject to a more considerable artificial disturbance (*e.g* physical disturbance by tides and digging during

the soil preparation for plantation) which may restrict the feasibility of assessing the changes in the degradation state in the relation with depth and other physico-chemical properties *e.g* redox-potential.

6 CONCLUSIONS

1. The grain size distribution, tidal inundation and vegetation are the factors which control the sediments characteristics in the study area. The high content of NH4+ at the abandoned saltpan resulted from the N fixation mediated by arbuscular mycorrhiza in Sea purslane roots. The content of NH4+ in the sediments inversely correlated to the pH in the aerobic layers. The absence of vegetation and the overwhelming dominance of sand at GH08 resulted in the lowest content of OC and N in the study area. The high NH4+ content at GH07 might relate to the stimulated N mineralization when the wet sediments were drained during the ebbs. The NH4+ content in the rainy season was higher than in the dry season, due to the increase of OC and N in the rainy season. However, the source of this OM supplement has not been determined in this study.

The data showed that P adsorbing on the carbonate grains were protected from phosphate solubilizer population. The deficiency of OM in the bare sediments caused the deficiency of P. The content of P in the study area inversely correlated to Eh, suggested that AP was liberated in the anoxic sediments. In the aerobic zone, the IP content did not strongly fluctuated along the transect, except for the peaks seen at GH05 and GH08, due to the immobilization pf P in the Ca-P complex. The low IP content at the mud flat was resulted from the desorption of P from the grains caused by the resuspension by tides. The IP:OP ratios showed that the pH and carbonate contents in the sediment influenced the P mineralization.

2. Chitin quantification by the binding with FITC-WGA resulted in the overestimation of sedimentary chitin. However, the chitin data reflected the relationship between the chitin content in sediments and the numbers of diatoms frustules – a source of chitin in coastal environments. Similarities among the variations of chitin~WGA, chitin~Gluam, and elemental compositions along the transect were also found. The chitin content calculated by Gluam showed that chitin contributed less than 2 % and 3 % to the sedimentary OC and nitrogen content. The dominant source of chitin may differ between the sampling sites. In the surface sediments of the interior sector, chitin might come from the macrobenthos while in the exterior sector, marine planktons seemed to be a more

dominant contributor to the chitin content. The monsoon regime probably influenced the chitin quantity of the interior sediments in the rainy season through the expansion of the tidal flooded area and, hence, marine plankton could reach further towards the hinterland. The higher content of chitin in the interior sediments in comparison with the exterior sites can be attributed to the dominance of silt-clay fraction in the interior sector which assisted the attachment of diatoms.

3. The sedimentary C:N ratio showed that the major source of OM probably originated from the sea in the past. During the salt production, the marine planktons in sea water intruded the salt-pan and accumulated there. The mangrove plantation in 1998, along with the intrusion of *Sesuvium portulacastrum*, resulted in the traces of terrestrial plants in the pool of OM in the surface sediments. As the OM content within the study area was relatively low, the THAA concentration was lower compared to other mangroves and coastal environments. The high temperature, along with the aeration of the sediments caused by the cracks on the surface, probably promoted the turnover rate of OM in the sediments. The concentration of amino acids in the sediments was affected by the plant biomass and amino acid composition of plant materials. The variation in depth-profiles of the individual amino acids between the sampling sites was probably resulted from the disturbances caused by dwelling-organisms and the preparation of soil for mangrove plantation.

The data showed that the nutritional state in the study area is influenced by the sediment characteristics. Moreover, it might relate to the activity of sediment bacteria, which is also affected by the sediment properties. Therefore, further studies on the coupling between sediment bacteria playing role in the N and P cycling will be needed to understand the dynamics of these essential elements in hypersaline areas. Such knowledge will be a potential tool for an effective pattern of mangrove plantation in harsh environment, besides the appropriate irrigational works.

REFERENCES

Aciego-Pietri, J.C. and Brookes, P.C., 2008. Nitrogen mineralization along a pH gradient of a silty loam UK soil. *Soil Biology and Biochemistry* 40(3), 797 – 802.

Ahemad, M. and Khan, M.S., 2010. Plant growth promoting activities of phosphate solubilizing *Entetobacter asburiae* as influenced by fungicides. *EurAsian Journal of BioSciences* 4, 88 – 95.

Akiyama M. and Johns W.D., 1972. Amino acids in the Cretaceous Pierre shale of eastern Wyoming. *Pacific Geology* 4, 79 – 89.

Alef, K. and Kleiner, D., 1987. Applicability of arginine ammonification as indicators of microbial activity in different soils. *Biology and Fertility of Soil* 5, 148 – 151.

Alkhatib, M., Schubert, C.J., Del Giorgio, P.A., Gelinas, Y. and Lehmann, M.F., 2012. Organic matter reactivity indicators in sediments of the St. Lawrence Estuary. *Estuarine, Coastal and Shelf Science* 102-103, 36 – 47.

Allen, A.K., Neuberger, A. and Sharon, N., 1973. The purification, composition and specificity of wheat-germ agglutinin. *Journal of Biochemistry* 131, 155 – 162.

Alongi, D.M., 1989. The fate of bacterial biomass and production in marine benthic food chains. In: Hattori, T., Ishida, Y., Maruyama, Y., Molita, R.Y. and Uchida, A. (Eds), Recent advances in microbial ecology. Japanese Scientific Societies Press, Tokyo, 353 – 359.

Alongi, D.M., 1994. The role of bacteria in nutrient recycling in tropical mangrove and other coastal benthic ecosystems. *Hydrobiologia* 285, 19 – 32.

Alongi, D.M., 2002. Present state and future of the world's mangrove forests. *Environmental Conservation* 29, 331 – 349.

Alongi, D.M., Boto, K.G. and Robertson, A.I., 1992. Nitrogen and phosphorus cycles. In: Robertson, A.I. and Alongi, D.M. (Eds), Tropical Mangrove Ecosystems. Coastal and Estuarine Studies. American Geophysical Unions, Washington, DC, 251 – 292.

Alongi, D.M., Christoffersen, P. and Tirendi, F., (1993). The influence of forest type on microbial-nutrient relationships in tropical mangrove sediments. *Journal of Experimental Marine Biology and Ecology* 171, 201 – 223.

Andersson E., Simoneit B.R. and Holm N.H., 2000. Amino acid abundances and stereochemistry in hydrothermally altered sediments from the Juan de Fuca Ridge, northeastern Pacific Ocean. *Applied Geochemistry* 15 (8), 1169 – 1990.

Asea, P.E.A., Kucey, R.M.N. and Stewart, J.W.B., 1988. Inorganic phosphate solubilization by two *Penicillium* species in solution culture and soil. *Soil Biology and Biochemistry* 20(4), 459 – 464.

Baba, S., Chan, H.T. and Aksornkoae, S., 2013. Useful Products from Mangrove and other Coastal Plants. ISME Mangrove Educational Book Series No. 3. International

Society for Mangrove Ecosystems (ISME), Okinawa, Japan, and International Tropical Timber Organization (ITTO), Yokohama, Japan.

Bashan, Y. and Holguin, G., 2002. Plant – growth promoting bacteria: a potential tool for arid mangrove reforestation. *Trees* 16: 159 – 166.

Bashan, Y. and Bashan, L.E., 2005. Plant-growth promoting. In: Hillel, D. (Ed), Encyclopedia of soils in the environments, Vol. 1. Elsevier, Oxford, UK, 103 – 115.

Bassler, B.L., Charles, Y., Lee, Y.C. and Roseman, S., 1991. Chitin utilization by marine bacteria. Degradation and catabolism of chitin oligosaccharides by Vibrio furnissii. *The Journal of Biological Chemistry* 266(36), 24276 – 24286.

Beena, K.R., Arun, A.B., Raviraja, N.S. and Sridhar, K.R., 2001. Association of arbuscular mycorhizal fungi with plants of coastal sand dunes of west coast of India. *Journal of Tropical Ecology* 42, 213 – 222.

Benner, R. and Kaiser, K., 2003. Abundance of amino sugars and peptidoglycans in marine particulate and dissolved organic matter. *Limnology and Oceanography* 48, 118 – 128.

Benner, R., 2003. Molecular indicators of the bioavailability of dissolved organic matter. In: Findlay S. and Sinsbaugh R. (Eds), Aquatic Ecosystems, Interactivity of Dissolved organic matter. Elsevier, 121 – 137.

Bernstein, L., 1975. Effects of salinity and sodicity on plant growth. *Annual Review of Phytopathology* 13, 295 – 312.

Biber, P.D., 2006. Measuring the effects of salinity stress in the red mangrove, *Rhizophora mangle* L.. *African Journal of Agricultural Research* 1(1), 1 – 4.

Blasco, F., 1984. Climatic factors and the biology of mangrove plants. In: Snedaker and Snedaker (Eds), The mangrove ecosystem, Research methods. UNESCO, 18 – 35.

Boon, A.R. and Duineveld, G.C.A., 1996. Phytopigments and fatty acids as molecular markers for the quality of near-bottom particulate organic matter in the North Sea. *Journal of Sea Research* 35, 279 – 291.

Boski, T., Pessoa, J., Pedro, P., Thorez, J., Dias, J.M.A. and Hall, I.R., 1998. Factors governing abundance of hydrolysable amino acids in the sediments from the N.W. European Continental Margin (47-50^{o}N). *Progress in Oceanography* 42, 145 – 164.

Boto, K.G. and Wellington, J.T., 1983. Phosphorus and nitrogen nutritional status of a northern Australian mangrove forest. *Marine Ecology Progress Series* 11, 63 – 69.

Boto, K.G., 1982. Nutrient and organic fluxes in mangroves. In: Clough, B.F. (Ed), Mangrove Ecosystems in Australia. ANU Press, Canberra, Australia, 239 – 257.

Boto, K.G., 1988. The phosphorus cycle. In: Agate, A.D., Subramanyam, C.V. and Vannucci, M. (Eds), Mangrove Microbiology. UNDP/UNESCO Regional Project (RAS/86/1988), New Delhi, India, 85 – 100.

Bouillon, S., Dahdouh-Guebas, F., Rao, A.V.V.S., Koedam, N. and Dehairs, F., 2003. Sources of organic carbon in mangrove sediments: variability and possible ecological implications. *Hydrobiologia* 495, 33 – 39.

Bradley, P.M. and Morris, J.T., 1990. Influence of oxygen and sulfide concentration on nitrogen uptake kinetics in *Spartina alterniflora*. *Ecology* 71, 282 – 287.

Bradley, P.M. and Morris, J.T., 1991. The influence of salinity on the kinetics of NH_4^+ uptake in *Spartina alterniflora*. *Oecologia* 85, 375 – 380.

Bridgham, S.D., Updegraff, K. and Pastor, J., 1998. Carbon, nitrogen, and phosphorus mineralization in northern wetlands. *Ecology* 79(5), 1545 – 1561.

Britto, D.T. and Kronzucker, H.J., 2002. NH_4^+ toxicity in higher plants: a critical review. *Journal of Plant Physiology* 159, 567 – 584.

Brown S.F., Baedecker M.J., Nissenbaum A. and Kaplan I.R., 1972. Early diagenesis in a reducing fjord, Saanich Inlet, British Columbia – III. Changes in organic constituents of sediment. *Geochimica et Cosmochimica Acta* 36, 1185 – 1203.

Brown, C.E., Pezeshki, S.R. and DeLaune, R.D., 2006. The effects of salinity and soil drying on nutrient uptake and growth of Spartina alterniflora in a simulated tidal system. *Environmental and Experimental* Botany 58, 140 – 148.

Brundrett, M., 1991. Mycorrhizas in Natural Ecosytems. In: Begon. M., Fitter, A.H. and Macfadyen, A. (Eds), Advances in Ecological Research Vol. 21. Academic Press Limited, Elsevier, 171 – 314.

Burdige, D.J. and Martens, C.S., 1988. Biogeochemical cycling in an organic-rich coastal marine basin: 10. The role of amino acids in sedimentary carbon and nitrogen cycling. *Geochimica et Cosmochimica Acta* 52, 1571 – 1584.

Buresh, R.J. and Patrick, W.H., 1978. Nitrate reduction to ammonium in aerobic soil. Soil *Science Society of America Journal* 42(6), 913 – 918.

Burger, M. and Jackson, L.E., 2003. Microbial immobilization of ammonium and nitrate in relation to ammonification and nitrification rates in organic and conventional cropping systems. *Soil Biology and Biochemistry* 35, 29 – 36.

Camilleri, J.C., 1992. Leaf-litter processing by invertebrates in a mangrove forest in Queensland. *Marine Biology* 114, 139 – 145.

Campbell, C.A., Schnitzer, M., Lafond, G.P., Zentner, R.P. and Knipfel, J.E., 1991. Thirty-year crop rotations and management practices on soil and amino nitrogen. *Soil Science Society of America Journal* 55, 739 – 745.

Carter, P.W. and Mitterer, R.M., 1978. Amino acid composition of organic matter associated with carbonate and non-carbonate sediments. *Geochimica et Cosmochimica Acta* 42, 1231 – 1238.

Casagrande, D.J. and Given, P.H., 1980. Geochemistry of amino acids in some Florida peat accumulation – II. Amino acids distributions. *Geochimica et Cosmochimica Acta* 44, 1493 – 1507.

Casagrande, D.J., 1974. Geochemistry of amino acids in some Florida peat accumulation – I. Analytical approach and total amino acid concentrations. *Geochimica et Cosmochimica Acta* 38, 419 – 434.

Chan, K.Y., Woo, M.L., Lo, K.W. and French, G.L., 1986. Occurrence and distribution of halophilic Vibrios in subtropical coastal waters of Hongkong. *Applied and Environmental Microbiology* 52(6), 1407 – 1411.

Chen, R. and Twilley, R.R., 1999. Patterns of Mangrove Forest Structure and Soil Nutrient Dynamics along the Shark River Estuary, Florida. *Estuaries* 22(4), 955 – 970.

Chen, Y.P., Rekha, P.D., Arun, A.B., Shen, F.T., Lai, W.A. and Young, C.C., 2006. Phosphate solubilizing bacteria from subtropical soil and their tricalcium phosphate solubilizing abilities. *Applied Soil Ecology* 34, 33 – 41.

Chhabra, R., 1996. Soil salinity and water quality. A.A. Balkema Publishers, Brookfiel, VT, 284 pages.

Christensen, B.T. and Bech-Andersen, S., 1989. Influence of straw disposal on distribution of amino acids in soil particle size faction. *Soil Biology and Biochemistry* 21, 35 – 40.

Cintron, G., Lugo, A.E., Pool, D.J. and Morris, G., 1978. Mangroves of arid environments in Puerto Rico and adjacent islands. *Biotropica* 10, 110 – 121.

Clough, B., 1998. Mangrove forest productivity and biomass accumulation in Hinchinbrook Channel, Australia. *Mangroves and Salt Marshes* 2, 191 – 198.

Clough, B., 2013. Continuing the Journey Amongst Mangroves. ISME Mangrove Educational Book Series No.1. International Society for Mangrove Ecosystem (ISME), Okinawa, Japan and International Tropical Timber Organization (ITTO), Yokohama, Japan.

Clough, B.F. and Attiwill P.M., 1975. Nutrient cycling in a community of Avicennia marina in a temperate region of Australia. In: Walsh, G.E., Snedaker, S.C. and Teas, H.J. (Eds), Proceedings of the international symposium on biology and management of mangroves. Institute of Food and Agriculture Sciences, University of Florida, Gainesville, Vol. 1, 137 – 146.

Cottrell, M.T. and Kirchman., 2000. Community composition of marine bacterioplankton determined by 16S rRNA gene clone libraries and fluorescence in sity hybridization. *Applied and Environmental Microbiology* 66, 5116 – 5122.

Cottrell, M.T., Wood, D.N., Yu, L. and Kirchman, D.L., 2000. Selected chitinase genes in cultured and uncultured marine bacteria in the alpha- and gamma-subclasses of the proteobacteria. *Applied and Environmental Microbiology* 66, 1195 – 1201.

Cowie J., Hedges, I. and Calvert, S.E., 1992. Sources and relative activities of amino acids, neutral sugars and lignin in an intermittently anoxic marine environment. *Geochimica et Cosmochimica Acta* 56, 1963 – 1978.

Cowie, G.L. and Hedges, J.I., 1992. Sources and relative reactivities of amino acids, neutral sugars and lignin in an intermittently anoxic marine environments. *Geochimica et Cosmochimica Acta* 56, 1963 – 1978.

Cowie, G.L. and Hedges, J.I., 1994. Biochemical indicators of diagenetic alteration in natural organic matter mixtures. *Nature* 369, 304 – 307.

Cowie, G.L., Hedges, J.I., Prahl, F.G. and De Lange, G.J., 1995. Elemental and major biochemical changes across an oxidation front in a relict turbidite: An oxygen effect. *Geochimica et Cosmochimica* Acta 59, 33 – 46.

Dahdouh-Guebas, R., 2006. Mangrove forest and tsunami protection. In: McGraw-Hill Yearbook of Science and Technology, McGraw-Hill Professional, New York, USA, 187 – 191.

Dakora, F.D. and Phillips, D.A., 2002. Root exudates as mediators of mineral acquisition in low-nutrient environments. *Plant and Soil* 245, 35 – 47.

Dauwe, B. and Middelburg, J.J., 1998. Amino acids and hexosamines as indicators of organic matter degradation state in North Sea sediments. *Limnology and Oceanography* 43(5), 782 – 798.

Dauwe, B., Middelburg, J.J. and Herman, P.M.J., 2001. *Effect of oxygen on the degradability of organic matter in subtidal and intertidal sediments of the North Sea area. Marine Ecology Progress Series* 215, 13 – 22.

Davis, J., Kaiser, K. and Benner, R., 2009. Amino acid and amino sugar yields and compositions as indicators of dissolved organic matter diagenesis. *Organic Geochemistry* 40, 343 – 352.

De Lange, G.J., van Os, B., Pruysers, P.A., Middelburg, J.J., Castradori, D., van Stanvoort, P., Müller, P.J., Eggenkamp, H. and Prahl, F.G., 1994. Possible early diagenetic alteration of palaeo proxies. In: Zahn, R., Pederson, T.F., Kaminski, M.A. and Laneyrie, L. (Eds), Carbon Cycling in the Glacial Ocean: Constraints on the Ocean's Role in Global Change. NATO ASI Series, I17, 225 – 258.

De Souza, M-J.B.D., Nair, S. and Chandramohan, D., 2000. Phosphate solubilizing bacteria around Indian peninsula. *Indian Journal of Marine Sciences* 29, 48 – 51.

Degens E.T., Reuter J.H. and Shaw K.N.F., 1964. Biochemical compounds in offshore California sediments and sea water. *Geochimica et Cosmochimica Acta* 28, 45 – 66.

Degens, E.T., 1970. Molecular nature of nitrogenous compounds in sea water and recent sediments. In: Hood, D.W. (Ed), Organic Matter in Natural Waters. Marine Scientific Instruments, University of Alaska, 77 – 106.

Dehairs, F., Rao, R.G., Chandra, M.P., Raman, A.V., Marguiller, S. and Hellings, L., 2000. Tracing mangrove carbon in suspended matter and aquatic fauna of the Gautami-Godavari Delta, Bay of Bengal, India. *Hydrobiologia* 431, 225 – 241.

DeKanel, J. and Morse, J.W., 1978. The chemistry of orthophosphateuptake from seawater on to calcite and aragonite. *Geochimica et Cosmochimica Acta* 42, 1335 – 1340.

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2011. Conservation and Development of the Kien Giang Biosphere Reserve Project.

Dissanayake, N.P. and Amarasena, K.M.C., 2009. Assessment and Comparison of salt Content in Mangrove Plants in Sri Lanka. *Ruhuna Journal of Science* 4, 21 – 27.

Dittmar, T. and Lara, R.J., 2001. Do mangroves rather than rivers provide nutrients to coastal environments south of the Amazon River? Evidence from long-term flux measurement. *Marine Ecology Progress Series* 213, 67 – 77.

Donald, W.W. and Mirocha, C.J., 1977. Chitin as a measure of fungal growth in stored corn and soybean seed. *Cereal Chemistry* 54(3), 466 – 474.

Dorota, M.B. và Halina, P.J., 2001. Seasonal variability of benthic ammonium release in the surface sediments of the Gulf of Gdansk (Southern Baltic Sea). Oceanologia. 43(1): 113-136

Durkin, C.A., Mock, T. and Armbrust, E.V., 2009. Chitin in diatoms and its association with the cell wall. *Eukaryotic Cell* 8(7), 1038 – 1050.

Einbu, A., 2007. Characterization of chitin and a study of its acid-catalyzed hydrolysis. PhD thesis, Norwegian University of Science and Technology, Norway, 15.

Emerson, S. and Hedges, J.I., 1988. Processes controlling the organic carbon content of open ocean sediments. *Paleoceanography* 3, 621 – 634.

Enwezor, W.O., 1967. Significance of C-organic|P ratio in mineralization of soil organic phosphorus. *Soil Science* 103, 62 – 66.

Estomata, N.L.B. and Abit, P.P., 2011. Growth and survival of mangrove seedlings under different levels of salinity and drought stress. *Annals of Tropical Research* 33(2), 107 – 129.

Fabre, A., Fromard, F. and Trichon, V., 1999. Fractionation of phosphate in sediments of four representative mangrove stages (French Guiana). *Hydrobiologia* 392, 13 – 19.

Fan, M.X. and Mackenzie, A.F., 1993. Urea and phosphate interactions in fertilizer microsites, ammonia volatilization and pH changes. *Soil Science Society of America Journal* 57, 839 – 845.

Fekete, A., Riemer, D.N. and Motto, H.L., 1976. A bioassay using common duckweed to evaluate the release of available phosphorus from pond sediments. *Journal of Aquatic Plant Management* 14, 19 – 25.

Feller, I.C. and Sitnik, M. (Eds), 1996. Mangrove ecology: a manual for a field course. Smithsonian Institution, Washington, DC.

Feller, I.C., 1995. Effects of nutrient enrichment on growth and herbivory of dwarf red mangrove (*Rhizophora mangle*). *Ecological Monographs* 65(4), 477 – 505.

Feller, I.C., 1996. Effects of nutrient enrichment on leaf anatomy of dwarf *Rhizophora mangle* L. (red mangrove). *Biotropica* 28(1), 13 – 22.

Feller, I.C., McKee, K.L., Whigham, D.F. and O'Neill, J.P., 2003. Nitrogen vs. phosphorus limitation across an ecotonal gradient in a mangrove forest. *Biogeochemistry* 62, 145 – 175.

Feller, I.C., Whigham, D.F., O'Neill, J.P. and McKee, K.L., 1999. Effects of nutrient enrichment on within-stand cycling in a mangrove forest. *Ecology* 80(7), 2193 – 2205.

Flores, P., Botella, M.A., Martinez, V. and Cerda, A., 2000. Ionic and osmotic effects on nitrate reductase activity in tomato seedlings. *Journal of Plant Physiology* 156, 552 – 557.

Friedel, J.K. and Scheller, E., 2002. Composition of hydrolysable amino acids in soil organic matter and soil microbial biomass. Soil Biology and Biochemistry 34, 315 – 325.

Fujimaki, H., Shimano, T., Inoue, M. and Nekane, K., 2006. Effect of a salt crust on evaporation from a bare saline soil. *Vadoze Zone Journal* 5, 1246 – 1256.

Funck D., Stadelhofer B. and Koch W., 2008. Ornithine – δ – aminotransferase is essential for arginine catabolism but not for proline biosynthesis. *BMC Plant Biol* 8, 40.

Furtado, J.I., Morgan, W.B., Pfafflin, J.R. and Ruddle, K. (Eds), 1990. Tropical Resources, Ecology and Development. Harwood Academic Publ. Chur. 306 pp.

Garcia, J.L., 1974. Reduction de l'oxy de nitreaux dans sols de rizeres du Senegal: measure de l'activite denitrificante. *Soil Biology and Biochemistry* 6, 78 – 84.

Garrity, G., Brenner, D.J., Krieg, N.R., and Staley, J.R. (Eds), 2005. Bergey's manual of systematic bacteriology. 2nd edition, vol. 2: The Proteobacteria, part B: The Gammaproteobacteria. Springer.

George, U.S. and Antoine, A.D., 1982. Denitrification potential of a salt marsh soil: effect of temperature, pH and substrate concentration. *Soil Biology and Biochemistry* 14, 117 – 125.

Giesen, W., Wulffraat, S., Zieren. M. and Scholten, L., 2007. Mangrove Guide Book for Southeast Asia. FAO and Wetland International, Thailand, 198 pages.

Gilman E., Ellison, J., Duke, N.C. and Field, C., 2008. Threats to mangrove from climate change and adaptation options, a review. *Aquatic Botany* 89(2), 237 – 250.

Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J. and Duke, N., 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography* 20, 154 – 159.

Giri, C., Zhu, Z., Tieszen, L.L., Singh, A. Gillette, S. and Kelmelis, J.A., 2008. Mangrove forest distributions and dynamics (1975-2005) of the tsunamis-affected region of Asia. *Journal of Biogeography* 35, 519 – 528.

Goldman, J.C. and Dennett, M.R., 1991. Ammonium regeneration and carbon utilization by marine bacteria grown on mixed substrates. *Marine Biology* 109, 369 – 378.

Goldstein, A.H., 1995. Recent progress in understanding the molecular genetics and biochemistry of calcium phosphate solubilization by Gram negative bacteria. *Biological Agriculture and Horticulture* 12, 185-193.

Gonzalez, J.M., Grimalt, J. and Albaiges, J., 1983. Amino acid composition of sediments from a deltaic environment. *Marine Chemistry* 14, 61 – 71.

Gooday, G.W., 1990. The ecology of chitin degradation. *Advances in Microbial Ecology* 11, 387 – 430.

Graevenits, A. and Carrington, G.O., 1973. Halophilic Vibrios from extraintestinal lesions in man. *Infection* 1, 54 – 58.

Grutters, M., van Raaphorst, W., Epping, E., Helder, W., de Leeuw, J.W., Glavin, D.P. and Bada, J., 2002. Preservation of amino acids from in situ-produced bacterial cell wall peptidoglycans in northeastern Atlantic continental margin sediments. *Limnology and Oceanography* 47(5), 1521 – 1524.

Guillizzoni, P., Marchetto, A., Lami, A., Cameron, G., Appleby, P., Schnell, N.L., Schnell, Ø.A., Belis, C.A., Giorgis, A. and Guzzi, L., 1996. The environmental history of a mountain lake (Lago Paione Superiore, Central Alps, Italy) for the last c. 100 years: a multidisciplinary, paleolimnological study. *Journal of Paleolimnology* 15, 245 – 264.

Gupta, L.P. and Kawahata, H., 2000. Amino acid and hexosamines composition and flux of sinking particulate matter in the equatorial Pacific at 175oE longitude. *Deep-Sea Reasearch* 1(47), 1937 – 1960.

Gupta, U.C. and Reuszer, H.W., 1967. Effect of plant species on the amino acid content and nitrification of organic matter. *Soil Science* 104, 395 – 400.

Hansen, H.P. and Grasshoff, K., 1983. The automated determination of dissolved inorganic phosphate. In: Grasshoff, K., Ehrhardt, M. and Kremling, F. (Eds), Methods of sea water analysis, 2nd edition, Verlag Chemie, 368 – 370.

Hansen, L.S. and Blackburn, T.H., 1991. Aerobic and anaerobic mineralization of organic material in marine sediments microcosms. *Marine Ecology Progress Series* 75, 283 – 291.

Harrison, A.F., 1982. Labile organic phosphorus mineralization in relationship to soil properties. *Soil Biology and Biochemistry* 14, 343 – 351.

Hatcher, B.G., Johannes, R.E., and Robertson, A.I., 1989. Review of research relevant to the conservation of shallow tropical marine ecosystems. *Oceanography and Marine Biology: An Annual Review* 27, 337 – 414.

Hatcher, P.G., Spiker, E.C., Szeverenyi, N.M., Maciel, G.E., 1983. Selective preservation and origin of petroleum-forming aquatic kerogen. *Nature* 305, 498 – 501.

Haugen, J.E. and Lichtentaler, R., 1991. Amino acid diagenesis, organic carbon and nitrogen mineralization in surface sediments from the inner Oslofjord, Norway. *Geochimica et Cosmochimica Acta* 55, 1649 – 1661.

Hedges J.I. and Prahl F.G., 1993. Early diagenesis, consequences for applications of molecular biomarkers. In: Engel, M.H. and Macko, S.A. (Eds), Organic geochemistry, principles and applications. Plenum, 237 – 253.

Hedges, J.I. and Keil, R.G., 1995. Sedimentary organic matter preservation, an assessment and speculative hypothesis. *Marine Chemistry* 49, 81 – 115.

Henrichs, S.M. and Farrington, J.W., 1980. Amino acids in interstitial waters of marine sediments: a comparison of results from varied sedimentary environments. In: Douglas, A.G. and Maxwell, J.R. (Eds), Advances in Organic Geochemistry, Pergamon Press, Oxford, 435 – 443.

Henrichs, S.M. and Farrington, J.W., 1984. Peru upwelling region sediments near 15^{o}S. 1. Remineralization and accumulation of organic matter. *Limnology and Oceanography* 29, 1 – 19.

Henrichs, S.M., 1987. Early diagenesis of amino acids and organic matter in two coastal marine sediments. *Geochimica et Cosmochimica* Acta 51, 1 – 15.

Herndl, G.J., Fagareli, J., Fanuko, N., Peduzzi, P. and Turk, V., 1987. Role of bacteria in the carbon and nitrogen flow between water-column and sediment in a shallow marine bay (Bay of Piran, Nothern Adriatic Sea). P.S.Z.N.I. *Marine Ecology* 8, 221 – 236.

Hesse, P.R., 1962. Phosphorus fixation in mangrove swamp muds. *Nature* 193, 295 – 296.

Hoang Van Huan, 2003. Scientific and technological study of methods of bank protection in estuaries, coastal zones of southern part. The Southern Institute of Water Resources Research. Origin in Vietnamese.

Hoch, M.P. and Kirchman, D.L., 1995. Ammonium uptake by heterotrophic bacteria in the Delaware estuary and adjacent coastal waters. *Limnology and Oceanography* 40(5), 886 – 897.

Hoch, M.P., Fogel, M.L. and Kirchman, D.L., 1992. Isotope fractionation associated with ammonium uptake by a marine bacterium. *Limnology and Oceanography* 37(7), 1447 – 1459.

Holan, Z., Votruba, J. and Vlasakova, V., 1980. New method of chitin determination based on deacetylation and gas liquid chromatographic assay of liberated acetic acid. *Journal of Chromatography* 190, 67 – 76.

Holguin G., Guzman M.A. and Bashan Y., 1992. Two new nitrogen – fixing bacteria from the rhizosphere of mangrove trees, their isolation, identification and in vitro

interaction with rhizosphere *Staphylococcus* sp.. *FEMS Microbiology Ecology* 101, 207 – 216.

Hollins, S. and Ridd, P.V., 1997. Evaporation over a tropical tidal salt flat. *Mangroves and Salt Marshes* 1, 95 – 102.

Horchani, F., Hajri, R. and Aschi-Smiti, S. (2011), Is the sensitivity to ammonium nutrition related to nitrogen accumualation?, *Current Botany* 2(2), 18-22.

Huntjens, J.L.M., 1972. Amino acid composition of humic acid-like polymers produced by streptomycetes and of humic acids from pasture and arable lands. *Soil Biology and Biochemistry* 4, 339 – 345.

Ingalls A.E., Lee C., Wakeham S.G. and Hedges J.I., 2003. The role of biominerals in the sinking flux and preservation of amino acids in the Southern Ocean along 1701W. *Deep Sea Research* II 50, 713 – 738.

Ittekkot, V., Deuser, W.G. and Degens, E.T., 1984. Seasonality in the fluxes of sugars, amino acids, and amino sugars to the deep ocean: Sargasso Sea. *Deep-Sea Research* 31, 1057 – 1069.

Ittekkot, V., Deuser, W.G., and Degens, E.T., 1984. Seasonality in the fluxes of sugars, amino acids, and amino sugars to the deep ocean: Sargasso Sea. *Deep-Sea Research* 31, 1057, 1069.

Ivanova, R., Bojinova, D. and Nedialkova, K., 2006. Rock phosphate solubilization by soil bacteria. *Journal of the University of Chemical Technology and Metallurgy* 41(3), 297 – 302.

Jenci, M. and Natarajan, S., Growth and organic constituent variations with salinity in *Excoecaria agallocha* L., an important halophyte. *Botany Research International* 2(1), 50 – 54.

Jenkinson, D.S. and Ladd, J.N., 1981. Microbial biomass in soil; measurement and turnover. In: Paul, E.A. and Ladd, J.N. (Eds), Soil Biochemistry Vol. 5. Dekker, New York, 415 – 471.

Jennerjahn, T.C. and Ittekkot, V., 1997. Organic matter in sediments in the mangrove areas and adjacent continental margins of Brazil: I. Amino acids and hexosamines. *Oceanologica Acta* 20(2), 359 – 369.

Jeuniaux, C., Voss-Foucart, M.F. and Bussers, J.C., 1982. Preliminary results on chitin biomass in some benthic marine biocenoses. In: Hirano, S. and Tokura, S. (Eds), Chitin and chitosan. Proceeding of the second international conference on chitin and chitosan, July 12-14. Japanese Society of chitin and chitosan, Sapporo, 200 – 204.

Jimenez, J.A., 1992. Mangrove forests of the Pacific coast of Central America. In: Seeliger, U. (Ed), Coastal plant communities of Latine America. Academic Press, San Diego, 259 – 267.

Joshi, A.J., 1980. Amino acids and mineral constituents in *Sesuvium portulacastrum* L., a salt marsh halophyte. *Aquatic Botany* 10, 69 – 74.

Joy, K.W., 1988. Ammonia, glutamine, and asparagines, a carbon-nitrogen interface. *Canadian Journal of Botany* 66, 2103 – 2109.

Joye, S.B. and Anderson, I., 2008. Nitrogen cycling in coastal sediments. In: Capone, D.G., Bronk, D.A., Carpenter, E.J. and Mulhollond, M.R. (Eds), Nitrogen in the Marine Environments, Elsevier, Amsterdam, 867 – 915.

Joye, S.B. and Hollibaugh, J.T., 1995. Sulfide inhibition of nitrification influences nitrogen regeneration in sediments. *Science* 270, 623 – 625.

Kamat, T. and Kerkar, S., 2011. Bacteria from salt pans: a potential resource of antibacterial metabolites. *Recent Research in Science and Technology* 3(9), 46 – 52.

Kathiresan, K. and Qasim, S.Z., 2005. Biodiversity of mangrove ecosystems. Hindustan Publishing Corporation, New Delhi, India, 4.

Kathiresan, K., Moorthy, P. and Ravikumar, S., 1996. A note on the influence of salinity and pH on rooting of *Rhizophora mucronata* Lamk. seedlings. *The Indian Foresters* 122 (8), 763 – 764.

Keeney, D.R. and Nelson, D.W., 1982. Nitrogen – inorganic forms. In: Page, A.L., Miller, R.H. and Keeney, D.R. (Eds), Methods of Soil Analysis, Part 2 – Chemical and Microbiological properties, 2nd edition. American Society of Agronomy, Inc. and Soil Science of America, Inc. Madison, Wl., pp. 643.

Keil, R.G., Tsamakis, E.C., and Hedges, J.I., 2000. Early diagenesis of particulate amino acids in marine systems. In: Goodfriend, G.A., Collins, M.J., Fogel, M.L., Macko, S.A, and Wehmiller, J.F. (Eds), Perspective in Amino Acid and Protein Chemistry, Oxford University Press, 69 – 82.

Kemp, A.L.W. and Mudrochova, A., 1973. The distribution and nature of amino acids and other nitrogen-containing compounds in Lake Ontorio surface sediments. *Geochimica et Cosmochimica Acta* 37, 2191 – 2206.

Khalil, M.I., Hossain, M.B. and Schmidhalter, U., 2005. Carbon and nitrogen mineralization in different upland soils of the subtropics treated with organic materials. *Soil Biology and Biochemistry* 37, 1507 – 1518.

Khan, A.A., Jilani, G., Akhtar, M.S., Naqvi, S.M.S. and Rasheed, M., 2009. Phosphorus solubilizing bacteria: occurrence, mechanisms and their role in crop production. *Journal of Agriculture and Biological Science* 1(1), 48 – 58.

Khan, A.G., 1974. The occurrence of mycorrhizas in halophytes, hydrophytes and xerophytes, and of endogone spores in adjacent soils. *Journal of General Microbiology* 81, 7 – 14.

Khan, S.O. and Sowden, F.J., 1972. Distributions of nitrogen in fulvic acid fractions extracted from the Black Solonetzic and Black Chernozemic soils of Alberta. *Canadian Journal of Soil Science* 52, 116 – 119.

Kim, K.Y., Jordan, D. and McDonald, G.A., 1998. *Enterobacter agglomerans* phosphate solubilizing bacteria and microbial activity in soil: Effect of carbon source. *Soil Biology and Biochemistry 30*(8-9), 995 – 1003.

Kim, K.Y., Jordan, D., Krishnan, H.B., 1997. *Rahnella aqualitis*, a bacterium isolated from soybean rhizosphere, can solubilize hydroxyapatite. *FEMS Microbiology Letters* 153, 273-277.

Kirchman, D.L., 1994. The uptake of inorganic nutrients by heterotrophic bacteria. Controls of the Microbial Loop, Nutrient Limitations. *Microbial Ecology* 28, 255 – 271.

Kissel, D.E., Sonon, L. Vendrell, P.F. and Isaac R.A., 2009. Salt concentration and measurement of soil pH. Communications in Soil Science and Plant Analysis 40, 179 – 187.

Knicker, H. and Hatcher, P.G., 1997. Survival of Protein in an Organic-Rich Sediment: Possible Protection by Encapsulation in Organic Matter. *Naturwissenschaften* 84, 231 – 234.

Koch, M.S., Benz, R.E. and Rudnick, D.T., 2001. Solid-phase phosphorus pools in highly organic carbonate sediments of northeastern Florida Bay. *Estuarine, Coastal and Shelf Science* 52, 279 – 291.

Kompleukou, K. and Tabatabai, M.A., 1994. Effect of organic acids on release of phosphorus from phosphate rocks. *Soil Science* 158, 442-453.

Kowalenko, C.G., 1978. Organic nitrogen, phosphorus and sulfur in soils. In: Schnitzer, M. and Khan, S.U. (Eds), Soil Organic Matter. Development of Soil Science 8. Elsevier, Amsterdam, 95 – 136.

Kruszewski, S., Wybranowski, T., Cyrankiewicz, M., Ziomkowska, B. and Pawlaczyk, A., 2008. Enhancement of FITC fluorescence by silver colloids and silver islands films. *Acta Physica Polonica A* 113(6), 1599 – 1608.

Kusum, A. and Aranuchalam, A., 2000. Effects of soil pH on nitrogen mineralization in regrowing humid subtropical forests of Meghalaya. *Journal of the Indian Society of Soil Science* 48(1), 98 – 101.

Lallier-Verges, E., Perrussel, B.P., Disnar, J.R. and Baltzer, F., 1998. Relationships between environmental conditions and the diagenetic evolution of organic matter derived from higher plants in a modern mangrove swamp system (Guadeloupe, French West Indies). *Organic Geochemistry* 29, 1663 – 1686.

Lara, R.J. and Cohen, M.C.L., 2006. Sediment porewater salinity, inundation frequency and mangrove vegetation height in Bragança, North Brazil: an ecohydrology-based empirical model. *Wetlands Ecology and Management* 14, 349 – 358.

Lara, R.J., Szlafsztein, C.F., Cohen, M.C.L., Oxmann, J., Schmitt, B.B. and Souza Filho, P.W.M., 2009. Geomorphology and sedimentology of mangroves and salt marshes, the formation of geobotanical units. In: Perillo, G.M.E., Wolanski, E., Cahoon, D. and Brinson, M.M. (Eds), Coastal Wetlands. Elsevier, Amsterdam, The Netherlands, 593 – 608.

Lathwell, D.J. and Grove, T.L., 1986. Soil – plant relationships in the tropics. *Annual Review of Ecology and Systematics* 17, 1 – 16.

Le Duc Tuan, Tran Thi Kieu Oanh, Cat Van Thanh and Nguyen Dinh Qui, 2002. Can Gio Mangrove Biosphere Reserve. Publisher of Agriculture, Ho Chi Minh City, Vietnam.

Lee C., Wakeham S. and Arnosti C., 2004. Particulate organic matter in the sea, the composition conundrum. *Ambio* 33, 565 – 575.

Lee C., Wakeham S.G. and Hedges J.I., 2000. Composition and flux of particulate amino acids and chloro pigments in equatorial Pacific seawater and sediments. *Deep Sea Research* I 47, 1535 – 1568.

Lee, C. and Cronin, C., 1982. The vertical flux of particulate nitrogen in the sea: Decomposition of amino acids in the Peru upwelling area and the equatorial Atlantic. *Journal of Marine Research* 40, 227 – 251.

Lee, S.Y., 1995. Mangrove outwelling: a review. *Hydrobiologia* 295, 203-212.

Lewis, W.M., 1987. Tropical Limnology. *Annual Review of Ecology and Systematics* 18, 159 – 184.

Liebezeit, G., 1993. Amino sugars in Bransfield Strait and Weddel Sea sediments. *Senckenbergiana Maritima* 23, 29 – 35.

Lindsay, W.L. and Vlek, P.L.G., 1977. Phosphate minerals. In: Dixon, J.B. and Weed, S.B. (Eds), Minerals in Soil Environments. Madison, Wisconsin: Soil Science of America Inc., 639 – 672.

Lonard, R.I. and Judd, F.W., 1997. The biological flora of coastal dunes and wetlands *Sesuvium portulacastrum* L.. *Journal of Coastal Research* 13, 96 – 104.

Long, M.H., McGlathery, K.J., Zieman, J.C. and Berg, P., 2008. The role of organic acid exudates in liberating phosphorus from seagrass-vegetated carbonate sediments. *Limnology and Oceanography* 53(6), 2616 – 2626.

Lovelock, C.E., Ball, M.C., Choat, B., Engelbrecht, B.M.J., Holbrook, N.M. and Feller, I.C., 2006. Linking physiological processes with mangrove forest structure: phosphorus deficiency limits canopy development, hydraulic conductivity and photosynthetic carbon gain in dwarf *Rhizophora mangle*. *Plant, Cell and Environment* 29, 793 – 802.

Lovelock, C.E., Feller, I.C., Ball, M.C., Engelbrecht, B.M.J. and Ewe, M.L., 2006. Differences in plant function in phosphorus- and nitrogen-limited mangrove ecosystems. *New Phytologist* 172, 514 – 522.

Lovelock, C.E., Feller, I.C., McKee, K.L., Engelbrecht, B.M.J. and Ball, M.C., 2004. The effect of nutrient enrichment on growth, photosynthesis and hydraulic conductance of dwarf mangroves in Panama. *Functional Ecology* 18, 25 – 33.

Lugo. A.E. and Snedaker, S.C., 1974. The ecology of mangroves. Annual *Review of Ecology and Systematics* 5, 39 – 64.

Luther, G.W., Kostka, J.E., Church, T.M., Sulzberger, B. and Stumm, W., 1992. Seasonal iron cyclingin in the salt-marsh sedimentary environment: the importance of ligand complexes with Fe(II) and Fe(III) in the dissolution of Fe(III) minerals and pyrite, respectively. *Marine Chemistry* 40, 81 – 103.

Machemer, S.D. and Wildeman, T.R., 1992. Adsoprtion compared with sulfide precipitation as metal removal processes from acid mine drainage in a constructed wetland. *Journal of Contaminant Hydrology* 9, 115 – 131.

Mandal, R. and Islam, A., 1978. Mineralization of inositol penta- and hexaphosphates in some soils of Bangladesh. *Bangladesh Journal of Soil Science* 6/7, 37 – 42.

Marchand, C., Lallier-verges, E., and Baltzer, F., 2003. The composition of sedimentary organic matter in relation to the dynamic features of a mangrove-fringed coast in French Guiana. *Estuarine Coastal and Shelf Science* 56(1), 119 – 130.

Mason, E., 1928. Note on the presence of mycorrhiza in the roots of salt marsh plants. *New Phytologist 27*(3), 193 – 195.

Mazda, Y., Magi, M., Kogo, M. and Phan Nguyen Hong, 1997. Mangroves as a coastal protection from waves in the Tong King Delta, Vietnam. *Mangroves and Salt Marshes* 1, 127 – 135.

McGill, W.B. and Cole, C.V., 1981. Comparative aspects of cycling of organic C, N, S, and P through soil organic matter. *Geoderma* 26, 267 – 286.

McGlathery, K.J., Marino, R., and Howarth, R.W., 1994. Variable rates of phosphate uptake by shallow marine carbonate sediments: mechanisms and ecological significance. *Biogeochemistry* 25, 127 – 146.

McIntire, P.E., Edenborn, H.M. and Hammack, R.W., 1990. Incorporation of bacterial sulfate reduction into constructed wetlands for the treatment of acid and metal mine drainage. Proc. 1990 National Symposium on Mining. University of Kentucky, Lexington, Kentucky. May 14-18. 1990. 207.

Meibom, K.L., Blokesch, M., Dolganov, N.A., Wu, C.Y. and Schoolnik, G.K., 2005. Chitin induces natural competence in *Vibrio cholerae*. *Science* 310, 1824 – 1827.

Mendoza, U.M.N., 2007. Dynamics of phosphorus and sulfur in a mangrove forest in Bragança, North Brazil. PhD Thesis, University of Bremen, Germany.

Mendoza, U.N., da Cruz, C.C., Menezes, M.P. and Lara, R.J., 2011. Flooding effects on phosphorus dynamics in an Amazonian mangrove forest, Northern Brazil. *Plant Soil* DOI 10.1007/s11104-011-1013-6.

Meyer-Reil, L.A., 1984. Bacterial biomass and heterotrophic activity in sediments and overlying waters. In: Hobbie, J.E. and Williams, P.le B. (Eds), Heterotrophic activity in the sea. Plenum Press, New York, 523 – 546.

Meyers, P.A., 1994. Preservation of elemental and isotopic source identification of sedimentary organic matter. *Chemical Geology* 114, 289 – 302.

Middelburg, J.J. and Nieuwenhuize, J., 2000. Nitrogen uptake by heterotrophic bacteria and phytoplankton in the nitrate-rich Thames estuary. *Marine Ecology Progress Series* 203, 13 – 21.

Miller, C., 2000. Understanding the Carbon-Nitrogen ratio. *A voice for Eco-Agriculture* 30(4), 20.

Mingju, X., Jiyang, S., Zhiqing, H. and Qizhong, W., 1991. Evolution of biomarkers in early diagenesis: organic geochemistry of Quaternary sediment in the Chiawobao basin. *Journal of Southeast Asian Earth Sciences* 5(1-4), 219-223.

Mölleken, H., Nitschke, J., Modick, H., Malolepszy, T., Altenback, H.J., 2011. A new colorimetric method to quantify β-1,3-1,6-glucans incomparison with total β-1,3-glucans and a method to quantify chitin in edible mushrooms. *Proceedings of the 7th International Conference on Mushroom Biology and Mushroom Products (ICMBMP7)*, 263 – 273.

Montgomery, M.T., Welschmeyer, N.A., Kirchman, D.L., 1990. A simple assay for chitin: application to sediment trap samples from the subarctic Pacific. *Marine Ecology Progress Series* 64, 301 – 308.

Montogomery, M.T. and Kirchman, D.L., 1993. Role of chitin-binding proteins in the specific attachment of the marine bacterium *Vibrio harveyi* to chitin. *Applied and Environmental Microbiology* 59, 373 – 379.

Montogomery, M.T. and Kirchman, D.L., 1994. Induction of chitin-binding proteins during the specific attachment of the marine bacterium *Vibrio harveyi* to chitin. *Applied and Environmental Microbiology* 60, 4284 – 4288.

Moran, M.A., Wicks, R.J. and Hodson, R.E., 1991. Export of dissolved organic matter from a mangrove swamp ecosystem: evidence from natural fluorescence, dissolved lignin phenols, and bacterial secondary production. *Marine Ecology Progress Series* 76, 175 – 184.

Morgan M.F., 1941. *Connecticut Agriculture Experiment Station Bulletin* 4, 450.

Moriarty, D.J.W., 1986. Measurement of bacterial growth rates in aquatic systems from rates of nucleic acid synthesis. *Advances in Microbial Ecology* 9, 245 – 292.

Morris, R.J., 1975. The amino acid composition of a deep-water marine sediment from the upwelling region northwest of Africa. *Geochimica et Cosmochimica Acta* 39, 381 – 388.

Mortimer, C.H., 1971. Chemical exchanges between sediments and water in the Great Lakes – speculations on probable regulatory mechanisms. *Limnology and Oceanography 16*, 387 – 404.

Müller, P.J., Suess, E., and Ungerer, C.A., 1986. Amino acids and amino sugars of surface particulate and sediment trap material from waters of the Scotia Sea. *Deep-Sea Research* 33, 819 – 838.

Murphy, J. and Riley, J.P., 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta* 27, 31 – 36.

Nga, B.T., Tinh, H.Q., Tam, D.T., Scheffer, M. and Roijackers, R., 2005. Young mangrove stands produce a large and high quality litter input to aquatic systems. *Wetlands Ecology and Management* 13, 569 – 576.

Nguyen Thi Gia Hang, unpublished. Diversity of benthic diatoms in Can Gio mangrove and coastal areas of the Mekong Delta. PhD thesis. University of Sciences, National University of Ho Chi Minh City, Vietnam.

Nguyen Van Hien, 2011. Considering the composition of some bacteria species participating in nitrogen and phosphorus cycle in sediments of mangrove at Ganh Hao, Bac Lieu (Mekong River Delta). MSc. thesis, University of Sciences, National University of Ho Chi Minh City, Viet Nam.

Nitschke, J., Altenbach, H.J., Malolepszy, T. and Mölleken, H., 2011. A new method for the quantification of chitin and chitosan in edible mushrooms. *Carbohydrate Research* 346, 1307 – 1310.

Odum, W.E. and Heald E.J., 1975. The detritus-based food web of an estuarine mangrove community. In: Cronin, L.E. (Ed), Estuarine Research. Academic Press Inc., New York, NY, USA, 265 – 286.

Odum, W.E., 1988. Comparative ecology of tidal fresh water and salt marshes. *Annual Review of Ecology and Systematics* 19, 147 – 176.

Ogawa, H., Amagai, Y., Koike, I., Kaiser, K. and Benner, R., 2001. Production of refractory dissolved organic matter by bacteria. *Science* 292, 917 – 920.

Ong J.E. and Gong, W.K., 2013. Structure, function and management of mangrove ecosystems. ISME Mangrove Educational Book Series No. 2. International Society for Mangrove Ecosystems (ISME), Okinawa, Japan and International Tropical Timber Organization (ITTO), Yokohama, Japan.

Ong, J.E. and Tan, K.H., 2008. Mangroves and sea-level change. In: Chan, H.T. and Ong, J.E. (Eds), Proceedings of the Meeting and Workshop on Guidelines for the Rehabilitation of Mangroves and Other Coastal Forests Damaged by Tsunamis and other Natural Hazards in the Asia-Pacific Region. Mangrove Ecosystems Proceeding No. 5. International Society for Mangrove Ecosystem (ISME), Okinawa, Japan, 89 – 96.

Ong, J.E., 1993. Mangroves – a carbon source and sink. *Chemosphere* 27(6), 1097 – 1107.

Oxmann, J.F., 2007. Influence of substrate physicochemical properties and organic matter interactions on phosphorus dynamics in replanted mangrove forests, Southern Vietnam. PhD thesis. University of Bremen.

Oxmann, J.F., Pham, Q.H., Schwendenmann, L., Stellman, J.M. and Lara, R.J., 2010. Mangrove reforestation in Vietnam: the effect of sediment physicochemical properties on nutrient cycling. *Plant Soil* 326, 225 – 241.

Parija, S.C., 2009. Textbook of Microbiology and Immunology. Elsevier, India, 315 – 317.

Park, S.H., Lee, J.H. and Lee, H.K., 2000. Purification and characterization of chitinase from a marine bacterium, Vibrio sp. 98CJ11027. *The Journal of Microbiology* 38(4), 224 – 229.

Passioura, J.B., Ball, M.C. and Knight, J.H., 1992. Mangroves may salinize the soil and in so doing limit their transpiration rate. *Functional Ecology* 6, 476 – 481.

Passioura, J.B., Ball, M.C. and Knight, J.H., 1992. Mangroves may salinize the soil and in so doing limit their transpiration rate. *Functional Ecology* 6, 476 – 481.

Pearce, F., 1996. Living sea walls keep floods at bay. *New Scientist* 150(2032), 7.

Pearce, F., 1999. An unnatural disaster. Clearing India's mangrove forest has left the coast defenseless. *New Scientist* 6, 12.

Pelet, R. and Debyser, Y., 1977. Organic geochemistry of Black Sea cores. *Geochimica et Cosmochimica Acta* 41, 1575 – 1586.

Pfeffer, C. and Oliver, J.D., 2003. A comparison of thiosulphate-citrate-bile salts-sucrose (TCBS) agar and thiosulphate-chloride-iodide (TCI) agar for the isolation of Vibrio species from estuarine environments. *Letter in Applied Microbiology* 36, 150 – 151.

Pham Quynh Huong, 2007. Driving forces behind nutrient dynamics in Khe Oc – a tidal creek in Can Gio Mangrove Biosphere Reserve, Ho Chi Minh City. MSc. thesis, University of Sciences, National University of Ho Chi Minh City, Viet Nam.

Pham Van Quy and research group, 2007. Nghiên cứu giải pháp trồng rừng trên đất ruộng muối ở rừng ngập mặn Cần Giờ. Management Board for Ho Chi Minh City Environmental Protection Forests.

Phan Nguyen Hong and Hoang Thi San, 1993. Mangrove in Vietnam. IUCN. The World Conservation Union, Bangkok, Thailand, 173 pp.

Phillips, N.W., 1984. Role of different microbes and substrates as potential food suppliers of specific essential nutrients to marine detritivores. *Bulletin of Marine Science* 35, 283 – 298.

Pomeroy, L.R. and Wiegert, R.G., 1981. Ecology of a salt marsh. *Ecological Studies Series*. Volume 38, Springer-Verlag, New York.

Portela, L.I., Coelho, C., Costa, S. and Freire, P., 2011. Hydrodynamic and sedimentary characteristics of a small tidal channel in the Ria de Aveiro. *Journal of Coastal Research* SI 64 (Proceedings of the 11th International Coastal Symposium), Szczecin, Poland, 1629 – 1632.

Poulicek, M. and Jeuniaux, C., 1982. Biomass and biodegradation of mollusk shell chitin in some marine sediments. In: Hirano, S. and Tokura, S. (Eds), Chitin and chitosan. Proceeding of the second international conference on chitin and chitosan, July 12-14. Japanese Society of chitin and chitosan, Sapporo,196 – 199.

Prahl, F.G., Ertel, J.R., Goni, M.A., Sparrow, M.A. and Eversmeyer, B., 1994. Terrestrial organic carbon contributions to sediments on the Washington margin. *Geochimica et Cosmochimica Acta* 58, 3035 – 3048.

Pruzzo, C., Vezzulli, L. and Colwell, R.R., 2008. Global impact of *Vibrio cholerae* interactions with chitin. *Environmental Microbiology* 10(6), 1400 – 1410.

Ravi, Z.P., 2005. Characterisation and distribution of amino acids in the mangrove sediments of Kochi. PhD thesis, Cochin University of Science and Technology, Cochin, India.

Reghunath, R. and Murthy, T.R.S., 1996. Carbonate organic matter studies of the shelf of Kasargod, West Coast of India. *Indian Journal of Marine Sciences* 25, 355 – 357.

Richardson, A.E., 2001. Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants. *Australian Journal of Plant Physiology* 28, 897 – 906.

Riemann, L. and Azam, F., 2002. Widespread N-acetyl-D-glucosamine uptake among pelagic marine bacteria and its ecological implications. *Applied and Environmental Microbiology* 68, 5554 – 5562.

Rittenberg S.C., Emery K.O., Hülsemann J., Degens E.T., Fay R.C., Reuter J.H., Grady, J.R., Richardson S.H. and Bray E.E., 1963. Biogeochemistry of sediments in experimental Mohole. *Journal of Sedimentary Petrology* 33, 140 – 172.

Riviera-Monroy, V.H. and Twilley, R.R., 1996. The relative role of denitrification and immobilization in the fate of inorganic nitrogen in mangrove sediments ((Terminos Lagoon, Mexico). *Limnology and Oceanography* 41, 284 – 296.

Rodriguez, H. and Fraga, R., 1999. Phosphate solubilizing bacteria and their role in plant growth promotion. *Biotechnology Advances* 17, 319 – 339.

Rojas A., Holguin G., Glick B.R. and Bashan Y., 1992. Synergism between *Phyllobacterium* sp. (N_2 – fixer) and *Bacillus licheniformis* (P – solubilizer), both from a semiarid mangrove rhizosphere. *FEMS Microbiology Ecology* 35, 181 – 187.

Roth, J., 1978. The biological functions of the lectins. 2. Wheat Germ Agglutinin. In: Roth, J. (Ed), The lectins: molecular probes in cell biology and membrane research. VEB Gustav Fischer Werlag, Jena, 21 – 23.

Ruess, R.W. and McNaughton S.J., 1987. Grazing and the dynamics of nutrient and energy-regulated microbial processes in the Serengeti grasslands. *Oikos* 49, 101 – 110.

Saenger, P., Hegerl, E.J. and Davie, J.D.S., 1983. Global status of mangrove ecosystems. Commission on Ecology Paper No. 3, IUCN. Gland, Switzerland, 88 pp.

Salsac, L., Chaillou, S., Morot-Gaudry, J.F., Lesaint, C. and Jolivoe, E., 1987. Nitrate and ammonium nutrition in plants. *Plant Physiology and Biochemistry* 25, 805 – 812.

Santisuk, T., 1989. Keys of terrestrial trees and shrubs recorded from mangrove formations in Thailand. In: Training Course of Life History of selected species of Flora and Fauna in Mangrove ecosystems. UNDP/Unesco Regional Project RAS/86/120 Bangkok, 115 – 128.

Sasekumar, A. and Loi, J.J., 1983. Litter production in three mangrove forest zones in the Malay Peninsula. *Aquatic Botany* 27, 283 – 290.

Schenk, M. and Wehrmann, J., 1979. The influence of ammonium in nutrient solution on growth and metabolism of cucumber plants. *Plant Soil* 52, 403 – 414.

Schmitt, B.B., 2006. Characterization of organic nitrogen compounds in sediment and leaves of a mangrove ecosystem in North Brazil. PhD Thesis. University of Bremen, Germany.

Schnitzer, M. and Khan, S.U. (Eds), 1978. Soil organic matter. Development in Soil Science 8. Elsevier, Amsterdam, Holland., 223.

Schroeder, R.A., 1975. Absence of beta-alanine and gamma-aminobutyric acid in cleaned foraminiferal shells: implication for use as a chemical criterion to indicate removal of non-indigenous amino acid contaminants. *Earth and Planetary Science Letters* 25, 274 – 278.

Seneca, E.D. and Broome, S.W., 1992. Restoring tidal marshes in North Carolina and France. In: Thayer, G.W. (Ed), Restoring the nation's marine environments. Maryland Sea Grant, College Park, Maryland, 53 – 78.

Sengupta, A. and Chaudhuri, S., 1991. Ecology of heterotrophic dinitrogen fixation in the rhizosphere of mangrove plant community at the Ganges river estuary in India. *Oecologia* 87, 560 – 564.

Senwo, Z.N and Tabatabai, M.A., 1998. Amino acid composition of soil organic matter. *Biology and Fertility of Soils* 26, 235 – 242.

Seo, D.C., Kewei, Y. and Delaune, R.D., 2008. Influence of salinity level on sediment denitrification in a Louisiana estuary receiving diverted Mississippi River water. *Archives of Agronomy and Soil Science* 54(3), 249 – 257.

Shahid, M., Hameed, S., Imran, A., Ali, S. and van Elsas, J.D., 2012. Root colonization and growth promotion of sunflower (*Helianthus annuus* L.) by phosphate solubilizing *Enterobacter* sp. Fs-11. *World Journal of Microbiology and Biotechnology* 28, 2749 – 2758.

Shapiro, R.E., 1958. Effect of flooding on availability of phosphorus and nitrogen. *Soil Science* 85(4), 190 – 197.

Sheldon, A., Menzies, N.W., So, H.B. and Dalal, R., 2004. The effect of salinity on plant available water. Super Soil 2004: 3rd Australian New Zealand Soils Conference, December 2004, University of Sydney, Australia.

Siddiqui, P.J. and Qasim, R., 1990. Litter production and physic-chemical conditions in mangrove, *Avicennia marina* (Forsk.) Vierh., swamps at Karachi back waters and Bakran creek. *Journal of Islamic Academy of Science* 3(1), 15 – 21.

Siezen, R.J. and Magne, T.H., 1978. Amino acids in suspended particulate matter from oceanic and coastal waters of the Pacific. *Marine Chemistry* 6, 215 – 231.

Silva, C.A.R. and Sampaio, L.S., 1998. Speciation of phosphorus in a tidal floodplain forest in the Amazon estuary. *Mangroves and Salt Marshes* 2, 51 – 57.

Singh, R.S., Raghubanshi, A.S., Singh, R.S. and Srivastava S.C., 1989. Microbial biomass acts as a source of plant nutrients in dry tropical forest and savannah. *Nature* 338, 499 – 500.

Singh, R.S., Srivastava, S.C., Raghubanshi, A.S., Singh, J.S. and Singh, S.P., 1991. Microbial C, N and P in dry tropical savannah, effects of burning and grazing. *Journal of Applied Ecology* 28, 869 – 878.

Slama, I., Messedi, D., Ghanaya, T., Savoure, A. and Abdelly, C. 2006. Effects of water deficit on growth and proline metabolism in *Sesuvium portulacastrum*. *Environmental and Experimental Botany* 56, 231 – 238.

Smith, H.J. and Burns, G.R., 1965. Ion gradients and nitrification associated with decomposition of a plant material layer in soil. *Soil Science Society of America Journal* 29(2), 179 – 181.

Smith, T.J., 1987. Seed predation in relation to tree dominance and distribution in mangrove forests. *Ecology* 68, 266 – 273.

Smucker, R.A. and Dawson, R., 1986. Products of photosynthesis by marine phytoplankton: chitin in TCA protein precipitates. *Journal of Experimental Marine Biology and Ecology* 104, 143 – 152.

Soto-Gil, R.W., 1988. Chitobiase and chitinase from Vibrio harveyi. PhD Thesis. University of California, San Diego and San Diego State University, San Diego, California, USA.

Sowden, F.J., 1968. Effect of long-term annual addition of various organic amendments on the nitrogenous components of a clay and a sand. *Canadian Journal of Soil Science* 48, 331 – 339.

Spalding, M., Kainuma, M. and Collins, L., 2010. World Atlas of Mangroves. London, Earthscan 319.

Steinberg, S.M., Venkatesan, M.I. and Kaplan, R., 1987. Organic geochemistry of sediments from the continental margin off Southern New England, U.S.A. I. Amino acids, carbohydrates and lignins. *Marine Chemistry* 21, 249 – 265.

Stevenson, F.J., 1956. Effect of some long-time rotations on the amino acid composition of the soil. *Soil Science of America Proceedings* 20, 204 – 208.

Stumm, W. and Morgan, J.J., 1981. Aquatic chemistry – an introduction emphasizing chemical equilibria in natural waters. John Wiley and Sons Inc, New York.

Subramanyam, C. and Rao, S.L.N., 1987. An enzymic method for the determination of chitin and chitosan in fungal cell walls. *Journal of Bioscience* 12(2), 125 – 129.

Suginta, W., Vongsuwan, A., Songsiriritthigul, C., Prinz, H., Estibeiro, P., Duncan, R.R., Svasti, J. and Fothergill-Gilmore, L.A., 2004. An endochitinase A from *Vibrio carchariae*: cloning, expression, mass and sequence analyses, and chitin hydrolysis. *Archives of Biochemistry and Biophysics* 424, 171 – 180.

Suresh, P.V., 2012. Biodegradation of shrimp processing bio-waste and concomitant production of chitinase enzyme and N-acetyl-D-glucosamine by marine bacteria: production and process optimization. *World Journal of Microbiology and Biotechnology* 28, 2945 – 2962.

Svitil, A.L., Chadhain, S.M.N., Moore, J.A. and Kirchman, D.L., 1997. Chitin degradation proteins produced by the marine bacterium Vibrio harveyi growing on different forms of chitin. *Applied and Environmental Microbiology* 63(2), 408 – 413.

Tam, N.F.Y., Wong, Y.S., Lan, C.Y. and Wang, L.N., 1998. Litter production and decomposition in a subtropical mangrove swamp receiving wastewater. *Journal of Experimental Marine Biology and Ecology* 226, 1 – 18.

Tenore, K.R., 1983. Organic nitrogen and caloric content of detritus. III. Effect on growth of a deposit feeding polychaete, *Capitella capitata*. *Estuary, Coastal and Shelf Science* 17, 733 – 742.

Thompson, F.L., Iida, T. and Swings, J., 2004. Biodiversity of Vibrios. *Microbiology and Molecular Biology Reviews* 68(3), 403 – 431.

Thompson, L.M., Black, C.A. and Zoellner, Z.A., 1954. Occurrence and mineralisation of organic phosphorus in soils, with particular reference to association with nitrogen, carbon and pH. *Soil Science* 77, 185 – 196.

Tran Ngoc Diem My, 2006. Vai trò của Sam biển (Sesuvium portulacastrum L.) đối với các tính chất lý hóa đất trong rừng ngập mặn Cần Giờ. MSc. Thesis. University of Sciencen, National University of Ho Chi Minh City, Vietnam.

Tungaraza, C., Brion, N., Rousseau, V., Baeyens, W. and Goeyens, L., 2003. Influence of bacterial activities on nitrogen uptake rates determined by the application of antibiotics. *Oceanologia* 45(3), 473 – 489.

Twilley, R.R., Chen, R.H. and Hargis, T., 1992. Carbon sinks in mangroves and their implications to carbon budget to tropical coastal ecosystems. *Water Air Soil Pollution* 64, 265 – 288.

Unger, D., Ittekkot, V., Schäfer, P. and Tiemann, J., 2005. Biogeochemistry of particulate organic matter from the Bay of Bengal as discernible from hydrolysable neutral carbohydrates and amino acids. *Marine Chemistry* 96, 155 – 184.

Uong Tan Lo, 1963. Lý luận sản xuất muối biển. Nxb. Công nghiệp, 55 – 77. Origin in Vietnamese.

Upadhyah, V.P., Ranjan, R. and Singh, J.S., 2002. Humam mangrove conflicts: The way out. *Current Science* 83(11), 1328 – 1336.

Vazquez P., Holguin G., Puent M.E. Lopez-Cortes A. and Bashan Y., 2000. Phosphate–solubilizing microorganisms associated with the rhizosphere of mangroves in a semiarid coastal lagoon. *Biology and Fertility of Soils* 30, 460 – 468.

Venkatesalu, V., Kumar, R.R. and Chellapan, K.P., 1994. Growth and mineral distribution of *Sesuvium portulacastrum* L., a salt marsh halophyte under sodium chloride stress. *Communication in Soil Science and Plant Analysis* 25, 2797 – 2805.

Veuger, B., Middelburg, J.J., Boschker, H.T.S., Nieuwenhuize, J., Van Rijswijk, P., Rochelle-Newall, E.J. and Navarro, N., 2004. Microbial uptake of dissolved organic and inorganic nitrogen in Randers Fjord. *Estuarine, Coastal and Shelf Science* 61, 507 – 515.

Vitorino, L.C., Silva, F.G., Soares, M.A., Souchie, E.L., Costa, A.C. and Lima, W.C., 2012. Solubilization of calcium and iron phosphate and in vitro production of Indolacetic acid by Endophytic isolates of *Hyptis marrubioides* Epling (Lamiaceae). *International Research Journal of Biotechnology* 3(4), 47-54.

Vitousek, P.M. and Sanford, R.L., 1986. Nutrient cycling in moist tropical forest. *Annual Review of Ecology and Systematics* 17, 137 – 167.

Wakeham, S.G., Hedges, J.I., Lee, C. and Pease, T.K., 1993. Effects of poisons and preservatives on the composition of organic matter in a sediment trap experiment. *Journal of Marine Research* 51, 669 – 696.

Wakeham, S.G., Lee, C., Hedges, J.I., Hernes, P.J. and Peterson, M.L., 1997. Molecular indicators of diagenetic status in marine organic matter. *Geochimica et Cosmochimica Acta* 61, 5363 – 5369.

Walsh, G.E., 1974. Mangrove, a review. In: Reinhold, R.J. and Queens, W.H. (Eds), Ecology of Halophytes. Academic Press, New York.

Wheeler, P.A. and Kirchman, D.L., 1986. Utilization of inorganic and organic nitrogen by bacteria in marine systems. *Limnology and Oceanography* 31, 998 – 1009.

Whelan, J.K., 1977. Amino acids in a surface sediment core of the Atlantic abyssal plain. *Geochimica et Cosmochimica Acta* 41, 803 – 810.

Whitney, D.M., Chalmers, A.G., Haines, E.B., Hanson, R.B., Pomeroy, L.R. and Sherr, B., 1981. The cycles of nitrogen and phosphorus. In: Pomeroy, L.R. and Wiegert, R.G. (Eds), The ecology of a salt marsh. Springer-Velag, New York, USA, 163 – 181.

Will, M.E. and Sylvia, D.M., 1990. Interaction of rhizosphere bacteria, fertilizer, and vesicular-arbuscular mycorrhizal fungi with sea oats. *Applied and Environmental Microbiology 56(7)*, 2073 – 2079.

Wolanski, E., 1986. An evaporation-driven salinity maximum zone in Australian tropical estuary. *Estuarine, Coastal and Shelf Science* 22, 415 – 424.

Woodroffe, C.D., 1985. Studies of a mangrove basin, Tuff Crater, New Zealand. I. Mangrove biomass and production of detritus. *Estuarine, Coastal and Shelf Science* 20, 265 – 280.

Xing, S.G., Jun, Y.B., Hau, Z.W. and Liang, L.Y., 2007. Higher accumulation of g-aminobutyric acid induced by salt stress through stimulation the activity of diamine oxidase in *Glycine max* (L.) Merr roots. *Plant Physiology and Biochemistry* 45, 560 – 566.

Ye Y., Tam N.F.Y., Lu C.Y. and Wong Y.S., 2005. Effects of salinity on germination, seedling growth and physiology of three salt-secreting mangrove species. *Aquatic Botany* 83, 193 – 205.

Yoshie, S., Noda, N., Tsuneda, S., Hirata, A. and Inamori, Y., 2004. Salinity decreases nitrite reductase gene diversity in denitrifying bacteria of wastewater treatment systems. *Applied and Environmental Microbiology* 70(5), 3152 – 3157.

Zhang, J., Zhang, R., Wu, Q. and Xu, N., 2012. Diagenetic alterations of amino acids and organic matter in the upper Pearl River Estuary surface sediments. *Biogeosciences* 9, 555-564.

William, M.A., Xia, K. and Michel, M., Protein as the dominant form of soil organic matter: more questions than answers about the role of enzymes in soils. ASA, CSSA and SSSA International Annual Meetings Nov. 3-6, Tampa, Florida, USA. http://scisoc.confex.com/crops/2013am/webprogram/Paper78433.html. Downloaded on July 29th, 2013.

Trees and Shrubs of the Maldives. ftp://ftp.fao.org/docrep/fao/010/ai387e/ai387e07.pdf. Downloaded on July 30th, 2013.

Table 1a: Grain size distribution in the sediments at each sampling station.

Station	Depth (cm)	Clay (%)		Fine silt (%)		Medium silt (%)		Coarse silt (%)		Fine sand (%)		Medium sand (%)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH01	00-05	15.51	17.15	29.86	33.16	36.44	40.31	11.14	9.02	7.06	0.37	0.00	0.00
GH01	05-10	16.46	18.34	31.04	34.43	38.57	42.02	11.92	5.22	2.02	0.00	0.00	0.00
GH01	10-15	18.24	19.38	33.33	36.88	41.31	41.69	7.03	2.05	0.11	0.00	0.00	0.00
GH01	30-35	17.44	18.86	34.78	38.78	42.47	40.32	5.20	2.04	0.11	0.00	0.00	0.00
GH02	00-05	11.64	12.42	22.55	24.08	36.10	34.85	17.68	15.07	12.03	13.58	0.00	0.00
GH02	05-10	14.10	16.39	25.98	31.09	44.27	39.34	14.80	11.73	0.85	1.45	0.00	0.00
GH02	10-15	14.93	17.90	28.15	32.30	39.15	37.38	15.42	11.08	2.35	1.34	0.00	0.00
GH02	30-35	17.66	19.51	32.99	35.61	44.21	38.24	5.15	6.35	0.00	0.29	0.00	0.00
GH03	00-05	11.18	10.85	19.16	20.91	36.80	36.44	27.02	24.27	5.85	7.54	0.00	0.00
GH03	05-10	11.94	13.82	19.48	25.81	36.84	36.79	27.97	19.27	3.76	4.31	0.00	0.00
GH03	10-15	12.86	15.59	21.63	29.27	37.54	40.31	22.32	13.50	5.65	1.33	0.00	0.00
GH03	30-35	17.41	16.56	35.47	34.75	39.23	41.74	7.58	6.69	0.32	0.26	0.00	0.00
GH04	00-05	14.75	15.66	27.89	29.67	43.43	40.57	13.63	13.20	0.29	0.91	0.00	0.00
GH04	05-10	16.21	15.17	28.94	27.50	45.63	41.15	9.09	14.73	0.13	1.45	0.00	0.00
GH04	10-15	16.36	17.23	30.72	31.60	38.87	40.28	11.26	10.55	2.80	0.35	0.00	0.00
GH04	30-35	17.09	18.86	32.01	35.47	37.92	41.58	10.47	4.09	2.51	0.00	0.00	0.00

Table 1b: Grain size distribution in the sediments at each sampling station (*cont*.).

Station	Depth (cm)	Clay (%)		Fine silt (%)		Medium silt (%)		Coarse silt (%)		Fine sand (%)		Medium sand (%)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH05	00-05	14.03	11.27	27.74	22.09	36.70	34.70	12.55	19.07	8.98	12.87	0.00	0.00
GH05	05-10	6.90	15.50	12.88	28.02	17.78	44.09	5.62	12.05	11.16	0.34	45.67	0.00
GH05	10-15	11.35	11.33	22.02	21.90	29.20	21.69	11.10	24.38	24.01	20.71	2.32	0.00
GH05	30-35	18.38	20.35	33.38	40.34	46.01	37.52	2.23	1.79	0.00	0.00	0.00	0.00
GH06	00-05	12.76	14.15	24.50	28.06	33.41	37.65	17.94	12.57	11.38	7.56	0.00	0.00
GH06	05-10	9.93	15.36	17.96	29.51	29.86	43.99	28.23	10.80	14.02	0.35	0.00	0.00
GH06	10-15	3.42	16.77	5.84	30.58	8.21	47.57	25.16	5.08	52.90	0.00	4.48	0.00
GH06	30-35	15.92	11.24	30.41	19.61	39.34	37.54	12.24	26.47	2.09	5.13	0.00	0.00
GH07	00-05	9.64	8.92	19.18	17.64	32.91	31.52	31.90	31.83	6.37	10.09	0.00	0.00
GH07	05-10	14.14	12.25	26.47	22.21	38.53	32.99	18.56	23.81	2.30	8.76	0.00	0.00
GH07	10-15	10.59	9.04	20.21	18.46	32.51	24.41	26.89	16.37	9.82	30.56	0.00	1.17
GH07	30-35	6.30	1.65	12.13	3.56	14.64	2.94	13.40	2.68	51.64	78.66	1.89	10.52
GH08	00-05	0.84	0.00	1.70	0.00	1.85	0.39	8.40	2.52	64.55	14.02	22.65	83.07
GH08	05-10	0.73	0.74	1.58	1.91	0.42	2.00	12.44	4.53	82.19	71.16	2.63	19.66
GH08	10-15	0.84	0.82	1.10	1.60	0.00	0.27	23.51	17.15	73.71	77.52	0.85	2.65
GH08	30-35	6.74	1.58	11.80	2.49	24.17	1.47	43.41	34.87	13.89	59.23	0.00	0.37

Table 2a: Physico-chemical properties of the sediments in the dry season.

Station	Depth (cm)	pH		Humidity (%)		Salinity (‰)		Eh (mV)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH01	00-05	6.67	5.92	28.09	18.65	49.38	89.55	254	260
GH01	05-10	6.59	7.10	23.35	21.96	67.65	55.69	286	250
GH01	10-15	6.54	6.65	25.14	24.17	54.89	54.55	285	265
GH01	30-35	6.20	7.15	32.51	32.84	44.26	40.98	257	187
GH02	00-05	6.48	7.31	31.74	29.63	17.74	31.65	151	243
GH02	05-10	6.44	7.05	27.33	25.00	38.03	54.62	205	249
GH02	10-15	6.47	7.1	26.01	25.15	44.98	51.03	250	262
GH02	30-35	6.26	6.83	27.88	27.85	44.28	50.09	258	267
GH03	00-05	7.38	6.83	17.71	41.11	40.74	17.97	140	226
GH03	05-10	7.30	6.71	38.27	24.31	19.79	31.94	-167	266
GH03	10-15	7.24	6.73	32.35	31.06	24.66	21.63	-208	276
GH03	30-35	7.15	6.76	39.58	34.09	26.17	26.44	-213	-59
GH04	00-05	7.78	6.65	29.57	25.59	44.94	76.46	175	263
GH04	05-10	7.64	7.28	27.35	26.85	50.93	47.36	173	258
GH04	10-15	7.59	7.34	27.01	25.29	44.75	41.07	224	255
GH04	30-35	7.00	7.19	28.71	26.36	39.78	33.12	281	176

Table 2b: Physico-chemical properties of the sediments in the dry season (*cont.*).

Station	Depth (cm)	pH		Humidity (%)		Salinity (‰)		Eh (mV)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH05	00-05	8.18	7.41	27.53	25.57	14.39	19.67	292	280
GH05	05-10	7.64	7.17	31.98	27.28	24.65	19.59	242	292
GH05	10-15	7.60	7.16	26.69	26.32	21.46	22.43	289	300
GH05	30-35	7.55	7.00	27.05	26.37	29.88	23.23	293	278
GH06	00-05	6.75	7.41	32.54	36.39	20.54	20.84	-100	148
GH06	05-10	6.57	7.07	32.33	37.53	25.12	22.68	109	-138
GH06	10-15	6.65	6.92	25.90	36.54	35.25	22.01	-104	-235
GH06	30-35	6.62	7.09	36.50	35.52	31.53	23.35	-203	-181
GH07	00-05	8.14	7.44	41.35	38.69	20.69	24.43	-16	-168
GH07	05-10	7.44	7.28	40.46	40.46	25.80	26.05	-220	-212
GH07	10-15	7.40	7.29	42.18	40.32	24.72	26.83	-239	-222
GH07	30-35	7.24	7.14	34.46	24.46	30.18	28.24	-208	-200
GH08	00-05	8.39	7.79	23.25	29.28	25.54	17.06	195	134
GH08	05-10	8.63	7.78	23.62	29.41	26.41	23.80	116	215
GH08	10-15	8.48	7.70	22.26	25.66	26.60	24.75	69	218
GH08	30-35	8.15	7.52	32.30	27.00	24.14	23.49	-213	-160

d

Table 3a: Physico-chemical properties of the sediments in the rainy season.

Station	Depth (cm)	pH		Humidity (%)		Salinity (ppt)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH01	00-05	7.53	7.59	30.13	29.81	26.76	29.66
GH01	05-10	7.52	7.29	24.74	24.92	44.73	46.18
GH01	10-15	7.26	7.25	25.31	26.14	51.57	41.19
GH01	30-35	6.86	7.12	34.73	32.58	37.33	43.92
GH02	00-05	7.10	7.08	32.17	30.00	15.90	23.83
GH02	05-10	7.09	7.19	30.16	27.52	31.26	36.92
GH02	10-15	6.99	7.15	25.58	26.43	31.58	38.68
GH02	30-35	6.80	6.65	26.48	27.57	45.46	53.34
GH03	00-05	7.38	7.19	37.37	32.05	11.56	18.71
GH03	05-10	7.45	7.24	36.07	29.62	14.91	23.61
GH03	10-15	7.22	7.16	36.29	30.06	20.23	24.11
GH03	30-35	7.08	7.01	40.37	38.64	29.50	26.49
GH04	00-05	7.58	7.37	31.36	28.43	17.01	33.57
GH04	05-10	7.37	7.23	27.93	29.46	29.15	47.17
GH04	10-15	7.29	7.27	28.07	27.79	27.21	41.12
GH04	30-35	7.00	7.04	29.66	25.94	29.00	35.76

Table 3b: Physico-chemical properties of the sediments in the rainy season (*cont.*).

Station	Depth (cm)	pH		Humidity (%)		Salinity (ppt)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH05	00-05	7.30	7.41	29.67	27.93	4.54	5.87
GH05	05-10	7.26	7.18	30.25	25.95	10.28	12.82
GH05	10-15	7.00	6.37	30.90	28.72	11.63	11.64
GH05	30-35	7.01	7.07	26.05	26.42	12.62	16.55
GH06	00-05	7.34	6.97	33.89	36.33	16.33	14.15
GH06	05-10	6.95	7.08	36.09	35.66	17.46	15.16
GH06	10-15	6.96	7.20	34.58	35.14	19.16	17.91
GH06	30-35	6.97	6.99	37.60	35.25	24.56	27.67
GH07	00-05	7.17	7.41	39.70	37.82	22.51	21.13
GH07	05-10	7.24	7.29	40.36	32.83	27.32	25.27
GH07	10-15	7.24	7.19	37.17	31.93	28.15	23.09
GH07	30-35	7.15	7.13	27.17	25.70	27.71	27.93
GH08	00-05	7.67	7.72	21.26	21.13	23.26	18.31
GH08	05-10	7.55	7.52	22.34	22.44	21.89	22.78
GH08	10-15	7.68	7.61	22.18	23.11	22.79	22.29
GH08	30-35	7.36	7.91	23.35	23.12	24.12	20.97

Table 4a: Sedimentary nutrient levels at each sampling site in the dry season.

Station	Depth (cm)	$NO_2^- + NO_3^-$ (µg.g^{-1})		$N\text{-}NH_4^+$ (µgN.g^{-1})		IP (µg P.g^{-1})		OP (µg P.g^{-1})		TP (µg P.g^{-1})		AP (µgP.g^{-1})	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH01	00-05	1.00	6.90	5.74	8.96	503.58	512.59	56.84	61.42	560.42	574.00	14.06	14.54
GH01	05-10	2.63	5.44	4.28	8.30	534.39	494.15	22.02	83.04	556.40	577.19	14.91	15.00
GH01	10-15	2.78	4.10	4.34	5.20	551.52	521.79	14.33	31.55	565.85	553.34	13.70	14.89
GH01	30-35	1.40	3.54	2.60	3.30	546.72	578.59	50.28	56.50	597.00	635.09	12.41	15.70
GH02	00-05	1.20	1.91	7.27	7.65	572.60	500.76	52.82	70.76	625.41	571.52	10.20	14.88
GH02	05-10	1.03	1.73	6.05	4.57	506.63	434.93	50.87	109.37	557.51	544.31	12.01	14.29
GH02	10-15	0.61	1.01	5.09	4.80	539.31	568.62	37.24	52.73	576.55	621.34	10.09	12.79
GH02	30-35	0.29	0.83	4.02	3.76	509.65	543.85	68.51	76.42	578.15	620.27	11.09	13.97
GH03	00-05	4.36	1.64	4.47	5.26	491.23	561.28	56.91	34.96	548.14	596.24	14.13	12.56
GH03	05-10	2.30	0.78	4.84	6.06	517.71	566.34	32.10	56.47	549.82	622.82	14.24	13.35
GH03	10-15	2.45	0.77	5.37	6.57	524.17	532.88	32.81	40.69	556.98	573.58	11.48	13.89
GH03	30-35	0.54	0.88	3.59	8.13	581.78	533.85	54.81	47.63	636.59	581.48	10.48	12.69
GH04	00-05	0.67	3.06	6.37	4.44	564.16	535.20	33.63	45.60	597.79	580.80	15.73	16.08
GH04	05-10	2.46	1.14	5.02	3.91	568.76	497.63	7.44	37.53	576.20	535.16	17.23	15.75
GH04	10-15	5.54	2.68	2.25	4.86	520.20	504.56	48.15	53.13	568.35	557.69	14.01	12.78
GH04	30-35	1.19	2.64	3.18	3.62	494.03	509.69	63.24	52.97	557.26	562.66	12.67	13.93

g

Table 4b: Sedimentary nutrient levels at each sampling site in the dry season (*cont.*).

Station	Depth (cm)	$NO_2^- + NO_3^-$ (µg.g^{-1})		$N\text{-}NH_4^+$ (µgN.g^{-1})		IP (µg P.g^{-1})		OP (µg P.g^{-1})		TP (µg P.g^{-1})		AP (µgP.g^{-1})	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH05	00-05	1.20	4.33	5.55	5.96	915.60	711.10	29.16	28.05	944.75	739.15	12.85	11.92
GH05	05-10	0.75	4.57	6.72	5.60	647.98	669.39	24.68	37.53	672.66	706.92	9.70	9.39
GH05	10-15	1.25	2.34	4.59	4.87	662.70	511.31	25.80	46.11	688.50	557.41	10.40	9.09
GH05	30-35	1.04	2.18	3.05	5.38	517.16	522.60	49.68	59.84	566.84	582.44	11.66	12.54
GH06	00-05	0.90	1.36	5.14	4.24	572.37	574.25	2.02	41.45	574.38	615.70	12.73	11.51
GH06	05-10	1.52	0.99	6.60	4.77	511.55	496.28	54.33	44.69	565.88	540.97	13.21	14.19
GH06	10-15	0.62	1.35	3.80	5.24	533.30	548.49	24.50	14.77	557.80	563.26	10.34	14.91
GH06	30-35	1.47	0.74	6.29	5.70	512.42	398.08	51.50	37.85	563.92	435.93	17.53	18.99
GH07	00-05	1.24	1.30	10.07	8.97	466.12	479.21	67.41	49.20	533.54	528.42	14.95	13.84
GH07	05-10	1.19	1.99	8.61	10.71	456.50	507.61	62.72	22.74	519.22	530.35	14.62	14.60
GH07	10-15	1.21	1.13	11.95	11.40	481.11	582.69	67.80	9.17	548.92	591.86	15.69	16.12
GH07	30-35	1.41	1.22	8.48	5.53	362.14	397.37	29.95	11.69	392.08	409.06	22.41	19.66
GH08	00-05	0.43	8.57	3.36	2.46	711.10	1183.63	16.12	26.98	727.23	1210.60	9.11	13.78
GH08	05-10	0.80	1.13	2.92	2.84	572.86	1204.95	20.28	87.07	593.14	1292.02	7.68	11.21
GH08	10-15	0.39	0.96	4.18	2.49	534.22	656.02	9.23	27.04	543.45	683.06	5.48	9.53
GH08	30-35	1.73	0.33	9.79	4.86	401.81	413.07	9.76	5.45	411.57	418.52	17.14	9.20

Table 5a: Sedimentary nutrient levels at each sampling site in the rainy season.

Station	Depth (cm)	$NO_2^- + NO_3^-$ (µg.g^{-1})		$N\text{-}NH_4^+$ (µg.g^{-1})		IP (µgP/g^{-1})		OP (µgP.g^{-1})		TP (µgP.g^{-1})		AP (µgP.g^{-1})	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH01	00-05	2.85	3.91	5.05	4.54	494.90	500.63	38.90	30.03	533.80	530.66	16.54	15.93
GH01	05-10	5.00	3.72	4.04	4.17	506.10	477.35	24.93	24.75	531.04	502.10	15.90	13.65
GH01	10-15	4.74	5.33	4.40	5.25	503.32	512.42	37.81	18.57	541.13	530.99	15.58	13.45
GH01	30-35	3.91	4.71	4.70	3.88	631.60	575.19	49.64	14.63	681.25	589.82	11.97	11.91
GH02	00-05	2.01	1.57	10.18	7.67	520.69	483.19	60.59	72.39	581.27	555.58	11.05	15.17
GH02	05-10	2.30	1.85	9.11	5.89	513.44	484.91	48.53	49.78	561.96	534.69	11.75	14.56
GH02	10-15	2.65	2.38	7.38	5.28	508.78	486.29	30.82	42.63	539.60	528.92	12.17	13.90
GH02	30-35	3.12	2.43	4.65	7.16	538.00	533.29	33.28	47.56	571.28	580.84	11.50	13.27
GH03	00-05	2.17	1.33	11.13	6.56	567.86	515.53	42.38	30.00	610.24	545.53	14.42	13.38
GH03	05-10	1.70	1.39	10.96	5.94	591.87	523.18	40.00	40.51	631.87	563.69	16.35	12.04
GH03	10-15	1.09	1.61	11.63	5.64	586.33	498.03	31.07	43.37	617.40	541.41	14.14	5.93
GH03	30-35	1.11	1.21	11.00	9.03	662.87	571.82	46.53	31.62	709.40	603.44	21.55	11.53
GH04	00-05	1.53	4.92	6.04	6.58	529.36	630.05	46.11	30.55	575.47	660.61	17.34	14.35
GH04	05-10	4.96	1.18	6.58	3.96	527.90	529.95	38.15	49.93	566.06	579.88	17.55	14.31
GH04	10-15	5.46	2.64	5.12	4.93	488.42	497.40	41.29	44.70	529.71	542.10	16.19	15.29
GH04	30-35	4.85	4.00	5.92	5.04	549.36	501.27	53.81	42.91	603.18	544.18	16.42	13.39

Table 5b: Sedimentary nutrient levels at each sampling site in the rainy season (*cont.*).

Station	Depth (cm)	$NO_2^- + NO_3^-$ (µg.g^{-1})		$N\text{-}NH_4^+$ (µgN.g^{-1})		IP (µg P.g^{-1})		OP (µg P.g^{-1})		TP (µg P.g^{-1})		AP (µgP.g^{-1})	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH05	00-05	2.44	2.25	11.82	10.94	835.39	623.83	46.81	36.83	882.20	660.66	14.61	11.25
GH05	05-10	1.93	2.01	8.95	6.65	654.95	690.48	61.97	17.73	716.93	708.21	9.21	9.91
GH05	10-15	3.00	1.43	9.14	5.90	582.22	562.05	61.98	29.16	644.20	591.21	8.81	10.02
GH05	30-35	1.92	1.91	4.59	4.60	534.82	497.86	33.09	36.05	567.91	533.91	12.80	10.98
GH06	00-05	2.23	2.08	4.50	10.53	604.84	591.46	27.86	25.99	632.70	617.45	13.71	13.39
GH06	05-10	1.44	2.41	3.90	8.73	556.00	593.44	41.48	30.53	597.47	623.96	11.05	12.73
GH06	10-15	1.18	2.29	4.78	9.29	548.78	588.61	33.50	31.12	582.28	619.74	10.28	13.48
GH06	30-35	1.47	0.96	6.00	6.60	552.18	479.02	28.46	14.84	580.64	493.86	20.92	17.78
GH07	00-05	1.67	1.50	10.18	7.82	452.47	466.39	20.72	29.79	473.19	496.18	12.91	13.52
GH07	05-10	1.53	1.49	11.80	9.40	455.18	530.85	37.01	11.63	492.19	542.48	13.57	13.14
GH07	10-15	1.61	1.42	11.20	9.54	471.87	501.86	24.92	26.63	496.79	528.49	14.00	14.25
GH07	30-35	1.18	1.10	6.66	6.66	395.27	317.84	9.39	17.21	404.66	335.05	15.29	10.44
GH08	00-05	2.98	1.42	2.77	3.04	574.98	578.30	12.15	33.97	587.13	612.27	4.80	3.21
GH08	05-10	2.12	1.95	2.93	3.23	616.89	579.99	12.62	19.48	629.52	599.47	6.60	3.33
GH08	10-15	2.13	0.84	3.41	4.03	539.85	509.24	26.52	25.31	566.37	534.55	13.41	3.04
GH08	30-35	1.07	1.02	3.97	3.13	517.28	431.89	30.57	14.75	547.84	446.64	6.97	6.90

Table 6a: Elemental composition in the sediments in the dry and rainy season.

Station	Depth (cm)	DRY SEASON				RAINY SEASON			
		%C_org		%N_tot		%C_org		%N_tot	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH01	00-05	0.859	0.882	0.108	0.095	0.684	0.606	0.076	0.069
GH01	05-10	0.603	0.659	0.082	0.079	0.544	0.418	0.064	0.053
GH01	10-15	0.546	0.628	0.082	0.077	0.562	0.498	0.065	0.067
GH01	30-35	0.499	0.511	0.082	0.074	0.553	0.546	0.064	0.070
GH02	00-05	1.178	0.971	0.107	0.097	1.392	0.992	0.123	0.101
GH02	05-10	0.706	0.494	0.084	0.072	0.924	0.688	0.095	0.078
GH02	10-15	0.591	0.469	0.063	0.059	0.571	0.487	0.059	0.055
GH02	30-35	0.556	0.554	0.071	0.067	0.552	0.563	0.065	0.067
GH03	00-05	0.787	0.824	0.075	0.076	1.249	1.066	0.083	0.094
GH03	05-10	0.618	0.926	0.068	0.090	1.437	0.956	0.091	0.080
GH03	10-15	0.599	0.750	0.069	0.077	0.918	0.714	0.082	0.074
GH03	30-35	0.618	1.140	0.076	0.102	1.039	0.817	0.103	0.090
GH04	00-05	0.932	0.732	0.089	0.071	0.971	0.697	0.098	0.060
GH04	05-10	0.628	0.578	0.076	0.071	0.895	1.001	0.088	0.080
GH04	10-15	0.564	0.445	0.069	0.060	0.609	0.622	0.078	0.067
GH04	30-35	0.607	0.617	0.072	0.071	0.561	0.486	0.120	0.056

Table 6b: Elemental composition in the sediments in the dry and rainy season (*cont.*).

Station	Depth (cm)	DRY SEASON				RAINY SEASON			
		%C_org		%N_tot		%C_org		%N_tot	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH05	00-05	0.643	0.697	0.067	0.077	1.242	0.835	0.094	0.083
GH05	05-10	1.031	0.607	0.105	0.070	1.137	0.455	0.095	0.050
GH05	10-15	0.455	0.550	0.056	0.067	1.241	0.564	0.108	0.071
GH05	30-35	0.510	0.539	0.077	0.079	0.523	0.453	0.062	0.057
GH06	00-05	0.750	0.789	0.074	0.081	0.597	0.866	0.070	0.078
GH06	05-10	0.798	0.986	0.080	0.097	0.625	0.712	0.074	0.072
GH06	10-15	0.326	1.140	0.033	0.078	0.653	0.694	0.076	0.061
GH06	30-35	0.716	1.137	0.074	0.089	1.076	0.755	0.097	0.072
GH07	00-05	0.853	0.664	0.086	0.074	0.525	0.506	0.062	0.054
GH07	05-10	0.831	0.907	0.100	0.087	0.619	0.470	0.065	0.049
GH07	10-15	1.036	0.913	0.100	0.078	0.586	0.546	0.063	0.059
GH07	30-35	0.502	0.222	0.044	0.025	0.336	0.061	0.034	0.013
GH08	00-05	0.204	0.208	0.018	0.032	0.032	0.029	0.041	0.004
GH08	05-10	0.141	0.302	0.017	0.034	0.029	0.041	0.012	0.014
GH08	10-15	0.068	0.126	0.014	0.023	0.053	0.037	0.012	0.010
GH08	30-35	0.896	0.415	0.063	0.024	0.054	0.055	0.015	0.013

Table 7a: Fractions of P in the sediments in the dry season.

Station	Depth (cm)	TP (µg P.g-1)		IP (µg P.g-1)		OP (µg P. g-1)		AP (µg P.g-1)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH01	00-05	560.42	574.00	503.58	512.59	56.84	61.42	14.06	14.54
GH01	05-10	556.40	577.19	534.39	494.15	22.02	83.04	14.91	15.00
GH01	10-15	565.85	553.34	551.52	521.79	14.33	31.55	13.70	14.89
GH01	30-35	597.00	635.09	546.72	578.59	50.28	56.50	12.41	15.70
GH02	00-05	625.41	571.52	572.60	500.76	52.82	70.76	10.20	14.88
GH02	05-10	557.51	544.31	506.63	434.93	50.87	109.37	12.01	14.29
GH02	10-15	576.55	621.34	539.31	568.62	37.24	52.73	10.09	12.79
GH02	30-35	578.15	620.27	509.65	543.85	68.51	76.42	11.09	13.97
GH03	00-05	548.14	596.24	491.23	561.28	56.91	34.96	14.13	12.56
GH03	05-10	549.82	622.82	517.71	566.34	32.10	56.47	14.24	13.35
GH03	10-15	556.98	573.58	524.17	532.88	32.81	40.69	11.48	13.89
GH03	30-35	636.59	581.48	581.78	533.85	54.81	47.63	10.48	12.69
GH04	00-05	597.79	580.80	564.16	535.20	33.63	45.60	15.73	16.08
GH04	05-10	576.20	535.16	568.76	497.63	7.44	37.53	17.23	15.75
GH04	10-15	568.35	557.69	520.20	504.56	48.15	53.13	14.01	12.78
GH04	30-35	557.26	562.66	494.03	509.69	63.24	52.97	12.67	13.93

m

Table 7b: Fractions of P in the sediments in the dry season (*cont.*).

Station	Depth (cm)	TP (µg P.g-1)		IP (µg P.g-1)		OP (µg P. g-1)		AP (µg P.g-1)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH05	00-05	944.75	739.15	915.60	711.10	29.16	28.05	12.85	11.92
GH05	05-10	672.66	706.92	647.98	669.39	24.68	37.53	9.70	9.39
GH05	10-15	688.50	557.41	662.70	511.31	25.80	46.11	10.40	9.09
GH05	30-35	566.84	582.44	517.16	522.60	49.68	59.84	11.66	12.54
GH06	00-05	574.38	615.70	572.37	574.25	2.02	41.45	12.73	11.51
GH06	05-10	565.88	540.97	511.55	496.28	54.33	44.69	13.21	14.19
GH06	10-15	557.80	563.26	533.30	548.49	24.50	14.77	10.34	14.91
GH06	30-35	563.92	435.93	512.42	398.08	51.50	37.85	17.53	18.99
GH07	00-05	533.54	528.42	466.12	479.21	67.41	49.20	14.95	13.84
GH07	05-10	519.22	530.35	456.50	507.61	62.72	22.74	14.62	14.60
GH07	10-15	548.92	591.86	481.11	582.69	67.80	9.17	15.69	16.12
GH07	30-35	392.08	409.06	362.14	397.37	29.95	11.69	22.41	19.66
GH08	00-05	727.23	1210.60	711.10	1183.63	16.12	26.98	9.11	13.78
GH08	05-10	593.14	1292.02	572.86	1204.95	20.28	87.07	7.68	11.21
GH08	10-15	543.45	683.06	534.22	656.02	9.23	27.04	5.48	9.53
GH08	30-35	411.57	418.52	401.81	413.07	9.76	5.45	17.14	9.20

n

Table 8a: Fractions of P in the sediments in the rainy season.

Station	Depth	TP (µg P.g-1)		IP (µg P.g-1)		OP (µg P.g-1)		AP (µg P.g-1)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH01	00-05	533.8	530.7	494.9	500.6	38.9	30.0	16.5	15.9
GH01	05-10	531.0	502.1	506.1	477.4	24.9	24.7	15.9	13.7
GH01	10-15	541.1	531.0	503.3	512.4	37.8	18.6	15.6	13.4
GH01	30-35	681.2	589.8	631.6	575.2	49.6	14.6	12.0	11.9
GH02	00-05	581.3	555.6	520.7	483.2	60.6	72.4	11.0	15.2
GH02	05-10	562.0	534.7	513.4	484.9	48.5	49.8	11.7	14.6
GH02	10-15	539.6	528.9	508.8	486.3	30.8	42.6	12.2	13.9
GH02	30-35	571.3	580.8	538.0	533.3	33.3	47.6	11.5	13.3
GH03	00-05	610.2	545.5	567.9	515.5	42.4	30.0	14.4	13.4
GH03	05-10	631.9	563.7	591.9	523.2	40.0	40.5	16.4	12.0
GH03	10-15	617.4	541.4	586.3	498.0	31.1	43.4	14.1	5.9
GH03	30-35	709.4	603.4	662.9	571.8	46.5	31.6	21.6	11.5
GH04	00-05	575.5	660.6	529.4	630.1	46.1	30.6	17.3	14.4
GH04	05-10	566.1	579.9	527.9	530.0	38.2	49.9	17.5	14.3
GH04	10-15	529.7	542.1	488.4	497.4	41.3	44.7	16.2	15.3
GH04	30-35	603.2	544.2	549.4	501.3	53.8	42.9	16.4	13.4

o

Table 8b: Fractions of P in the sediments in the rainy season (*cont.*).

Station	Depth	TP (µg P.g-1)		IP (µg P.g-1)		OP (µg P.g-1)		AP (µg P.g-1)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH05	00-05	882.2	660.7	835.4	623.8	46.8	36.8	14.6	11.3
GH05	05-10	716.9	708.2	655.0	690.5	62.0	17.7	9.2	9.9
GH05	10-15	644.2	591.2	582.2	562.1	62.0	29.2	8.8	10.0
GH05	30-35	567.9	533.9	534.8	497.9	33.1	36.1	12.8	11.0
GH06	00-05	632.7	617.4	604.8	591.5	27.9	26.0	13.7	13.4
GH06	05-10	597.5	624.0	556.0	593.4	41.5	30.5	11.0	12.7
GH06	10-15	582.3	619.7	548.8	588.6	33.5	31.1	10.3	13.5
GH06	30-35	580.6	493.9	552.2	479.0	28.5	14.8	20.9	17.8
GH07	00-05	473.2	496.2	452.5	466.4	20.7	29.8	12.9	13.5
GH07	05-10	492.2	542.5	455.2	530.9	37.0	11.6	13.6	13.1
GH07	10-15	496.8	528.5	471.9	501.9	24.9	26.6	14.0	14.3
GH07	30-35	404.7	335.1	395.3	317.8	9.4	17.2	15.3	10.4
GH08	00-05	587.1	612.3	575.0	578.3	12.1	34.0	4.8	3.2
GH08	05-10	629.5	599.5	616.9	580.0	12.6	19.5	6.6	3.3
GH08	10-15	566.4	534.6	539.9	509.2	26.5	25.3	13.4	3.0
GH08	30-35	547.8	446.6	517.3	431.9	30.6	14.8	7.0	6.9

Table 9a: Chitin~FITC in the sediments in the dry and rainy season.

Site	Depth (cm)	chitin-FITC (mg/g)			
		DRY SEASON		RAINY SEASON	
		transect 1	transect 2	transect 1	transect 2
GH01	00-05	56.96	55.49	53.93	51.86
GH01	05-10	56.56	58.95	63.20	43.66
GH01	10-15	54.23	61.92	68.72	55.78
GH01	30-35	57.13	73.14	67.22	53.87
GH02	00-05	51.05	56.41	44.43	47.73
GH02	05-10	53.20	47.20	47.33	101.63
GH02	10-15	46.55	45.99	53.98	67.19
GH02	30-35	63.05	54.17	49.16	79.79
GH03	00-05	52.42	46.24	37.17	67.29
GH03	05-10	42.77	43.57	35.51	70.80
GH03	10-15	53.29	48.18	39.28	57.61
GH03	30-35	83.76	47.26	47.86	106.55
GH04	00-05	52.99	39.81	40.67	78.49
GH04	05-10	53.60	36.80	41.22	56.24
GH04	10-15	43.96	31.47	44.99	68.87
GH04	30-35	52.52	58.75	49.69	67.26

q

Table 9b: Chitin~FITC in the sediments in the dry and rainy season (*cont.*).

Site	Depth (cm)	chitin-FITC (mg/g)			
		DRY SEASON		RAINY SEASON	
		transect 1	transect 2	transect 1	transect 2
GH05	00-05	35.06	42.68	33.44	43.04
GH05	05-10	45.41	36.15	37.49	45.86
GH05	10-15	38.79	43.11	42.79	60.62
GH05	30-35	65.14	56.84	42.01	51.34
GH06	00-05	51.76	47.12	53.27	59.48
GH06	05-10	47.65	65.11	58.64	74.77
GH06	10-15	25.58	64.05	58.58	52.33
GH06	30-35	51.43	62.76	59.40	64.14
GH07	00-05	53.63	35.00	37.30	32.47
GH07	05-10	42.47	44.68	34.12	30.07
GH07	10-15	44.02	38.66	33.61	29.66
GH07	30-35	46.76	38.03	31.79	13.63
GH08	00-05	14.51	19.73	8.58	16.29
GH08	05-10	13.17	18.79	12.63	16.26
GH08	10-15	15.27	15.33	12.23	8.14
GH08	30-35	41.37	18.87	12.31	15.12

r

Table 10a: Glucosamine and galactosamine in the sediments in the dry and rainy season.

Sample	Depth (cm)	DRY SEASON				RAINY SEASON			
		Gluam (µg/g)		Galam (µg/g)		Gluam (µg/g)		Galam (µg/g)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH01	00-05	216.54	210.30	135.69	130.62	176.76	222.19	111.55	132.66
GH01	05-10	147.30	178.60	98.09	118.03	138.80	152.61	91.57	98.33
GH01	10-15	156.84	159.97	106.81	106.87	146.18	151.31	96.62	95.58
GH01	30-35	147.99	152.83	108.58	114.19	143.39	149.38	107.63	104.15
GH02	00-05	254.74	240.95	161.96	145.68	217.94	203.65	126.87	116.62
GH02	05-10	203.55	160.29	128.31	109.98	149.53	131.99	89.22	78.86
GH02	10-15	137.36	131.52	91.24	93.95	131.82	123.77	86.15	86.85
GH02	30-35	152.61	159.25	106.89	109.99	149.91	152.31	101.16	98.46
GH03	00-05	161.08	170.38	103.02	109.02	83.44	146.15	48.38	76.60
GH03	05-10	147.12	204.74	99.71	137.25	81.38	180.31	44.83	113.32
GH03	10-15	168.93	169.42	113.71	116.78	73.59	174.38	47.38	116.45
GH03	30-35	159.31	235.28	116.56	166.59	96.12	89.42	65.65	58.52
GH04	00-05	217.78	180.19	138.97	111.83	200.98	157.54	131.09	94.77
GH04	05-10	189.07	171.61	125.35	111.86	186.87	154.48	117.48	91.17
GH04	10-15	165.55	137.45	112.05	93.00	166.86	141.56	109.21	86.04
GH04	30-35	167.89	162.39	119.91	110.22	148.43	182.16	106.13	119.58

Table 10b: Glucosamine and galactosamine in the sediments in the dry and rainy season (*cont.*).

Sample	Depth (cm)	DRY SEASON				RAINY SEASON			
		Gluam (µg/g)		Galam (µg/g)		Gluam (µg/g)		Galam (µg/g)	
		transect 1	transect 2	transect 1	transect 2	transect 1	transect 2	transect 1	transect 2
GH05	00-05	129.58	111.80	85.04	82.02	89.72	163.44	53.32	108.80
GH05	05-10	216.01	129.87	141.26	96.18	171.23	54.15	112.46	39.56
GH05	10-15	104.69	126.29	74.19	86.34	43.39	58.61	28.79	39.73
GH05	30-35	157.57	158.79	102.72	104.53	116.64	64.88	80.03	42.78
GH06	00-05	191.64	171.44	129.45	114.47	125.83	65.56	92.87	44.57
GH06	05-10	159.56	223.71	106.14	147.65	133.25	80.36	91.94	55.00
GH06	10-15	66.53	226.24	46.42	155.37	71.24	74.41	51.68	51.42
GH06	30-35	167.86	228.38	112.59	155.90	99.38	62.42	69.77	43.86
GH07	00-05	238.65	165.16	153.05	106.04	144.47	124.57	96.81	79.81
GH07	05-10	277.43	208.23	179.53	133.94	155.89	173.92	102.74	114.61
GH07	10-15	286.14	188.54	177.22	126.14	239.69	193.88	158.95	128.31
GH07	30-35	105.97	43.16	76.62	35.10	64.85	25.76	49.35	30.28
GH08	00-05	26.48	32.13	28.67	36.59	25.71	24.90	25.03	23.83
GH08	05-10	16.87	34.90	18.15	40.95	16.32	38.34	16.60	38.86
GH08	10-15	11.58	18.18	11.24	20.38	6.47	11.76	6.40	11.98
GH08	30-35	262.54	58.35	169.96	44.62	79.17	41.23	73.78	39.43

t

Table 11a: Mole % of the amino acids in the sediments of transect 1 in the dry season.

Station	Depth (cm)	Tau	Asp	Thr	Ser	Glu	Gly	Ala	Val	Met	Ile	Leu	Tyr	Phe	b-Ala	g-Aba	His	Orn	Lys	Arg
GH01	00-05	0.18	13.42	5.93	6.31	12.72	15.04	10.69	6.38	0.11	3.77	6.22	0.81	3.28	1.96	1.41	1.41	0.52	4.35	3.11
GH01	05-10	0.23	13.50	5.60	5.83	13.34	14.79	10.67	6.16	0.14	3.64	5.93	0.51	3.15	2.40	1.81	1.32	0.59	4.45	3.04
GH01	10-15	0.24	14.20	4.85	5.29	13.96	15.10	10.81	6.01	0.00	3.42	5.54	0.26	2.93	2.67	1.95	1.39	0.62	4.50	2.78
GH01	30-35	0.25	14.65	5.15	5.09	13.65	15.01	10.24	5.75	0.00	3.04	4.71	0.00	2.30	3.69	2.65	1.25	0.70	5.24	2.45
GH02	00-05	0.15	14.26	6.35	6.74	12.92	13.81	10.84	6.72	0.15	4.00	6.63	1.35	3.47	1.27	0.86	1.36	0.40	3.79	3.22
GH02	05-10	0.18	14.49	6.26	6.34	12.95	14.09	10.74	6.43	0.00	3.70	5.94	0.53	3.16	1.92	1.36	1.44	0.50	4.34	2.99
GH02	10-15	0.23	14.04	5.59	5.89	13.65	14.61	10.44	6.10	0.00	3.37	5.52	0.18	2.84	2.54	1.84	1.56	0.57	4.58	3.00
GH02	30-35	0.22	13.98	5.64	5.69	13.43	14.64	10.44	6.10	0.00	3.50	5.57	0.18	2.86	2.71	1.98	1.45	0.60	4.67	2.82
GH03	00-05	0.17	13.94	6.15	6.37	12.26	14.33	10.48	6.92	0.12	3.93	6.32	0.83	3.28	1.51	1.17	1.55	0.95	4.46	3.05
GH03	05-10	0.17	14.27	6.04	6.12	12.42	14.42	10.36	6.64	0.13	3.69	5.86	0.54	3.10	1.76	1.33	1.57	1.04	4.79	2.94
GH03	10-15	0.19	14.52	6.00	5.93	12.77	14.38	10.37	6.45	0.00	3.33	5.24	0.31	2.88	2.07	1.64	1.69	1.18	4.97	2.81
GH03	30-35	0.23	14.95	5.47	5.31	12.95	14.36	10.17	6.32	0.00	3.20	4.89	0.21	2.56	2.78	2.20	1.64	1.40	5.09	2.37
GH04	00-05	0.17	13.78	6.10	6.42	12.36	14.48	10.42	6.69	0.14	3.82	6.09	0.87	3.19	1.66	1.33	1.55	1.06	4.55	3.08
GH04	05-10	0.20	14.23	5.86	5.72	12.93	14.40	10.53	6.45	0.00	3.51	5.52	0.32	2.88	2.18	1.89	1.55	1.18	4.71	2.87
GH04	10-15	0.21	14.71	5.82	5.58	13.47	14.29	10.55	6.31	0.00	3.41	5.34	0.25	2.81	2.22	1.93	1.50	1.19	4.52	2.81
GH04	30-35	0.29	14.99	5.41	5.23	13.86	14.40	10.74	6.30	0.00	3.12	4.82	0.23	2.56	2.64	2.07	1.50	1.41	4.94	2.51

u

Table 11b: Mole % of the amino acids in the sediments of transect 1 in the dry season (*cont.*).

Station	Depth (cm)	Tau	Asp	Thr	Ser	Glu	Gly	Ala	Val	Met	Ile	Leu	Tyr	Phe	b-Ala	g-Aba	His	Orn	Lys	Arg
GH05	00-05	0.18	14.34	5.86	6.27	12.38	14.51	9.96	6.26	0.00	3.33	5.46	0.22	2.95	1.75	1.00	1.92	1.06	4.85	3.05
GH05	05-10	0.16	14.34	6.14	6.46	12.45	14.85	10.02	6.56	0.00	3.71	5.84	0.63	3.10	1.60	1.06	1.78	0.90	4.78	3.10
GH05	10-15	0.19	14.46	5.77	5.88	12.87	14.06	10.04	6.27	0.00	3.27	5.16	0.25	2.80	2.18	1.59	1.81	1.17	5.13	2.87
GH05	30-35	0.25	17.17	5.81	5.66	0.98	16.17	12.12	7.26	0.00	3.70	5.72	0.18	3.07	3.38	2.60	1.92	1.55	5.40	2.98
GH06	00-05	0.19	14.44	6.08	6.17	12.25	15.06	9.93	6.37	0.10	3.65	5.53	1.25	3.01	2.00	1.46	1.62	1.01	4.82	2.81
GH06	05-10	0.49	13.98	6.09	6.17	11.77	13.94	10.46	6.72	0.16	3.84	5.88	1.22	3.09	1.89	1.26	1.94	1.07	5.09	2.82
GH06	10-15	0.17	14.76	6.23	6.20	11.79	14.31	10.15	6.70	0.15	3.60	5.50	1.15	3.04	1.57	1.18	1.84	1.00	4.96	2.76
GH06	30-35	0.19	15.18	6.09	6.00	12.20	14.64	10.08	6.40	0.20	3.47	5.15	1.09	2.84	2.05	1.71	1.80	1.19	5.04	2.52
GH07	00-05	0.26	14.18	6.46	6.73	11.60	13.95	10.24	6.50	0.00	3.81	5.93	1.58	3.31	1.67	1.07	1.51	0.90	4.82	3.26
GH07	05-10	0.23	14.13	6.50	6.84	11.34	14.29	10.28	6.51	0.00	3.76	5.88	1.06	3.28	1.65	1.18	1.53	0.84	4.77	3.22
GH07	10-15	0.26	14.29	6.38	6.61	11.34	14.29	10.18	6.63	0.00	3.85	5.87	1.71	3.27	1.77	1.18	1.54	0.89	4.76	3.14
GH07	30-35	0.39	14.06	5.68	5.48	10.87	14.69	9.88	6.59	0.00	3.78	5.62	1.60	3.20	2.44	1.81	1.78	1.18	5.04	3.03
GH08	00-05	0.26	13.69	6.32	5.83	10.64	13.47	10.22	6.89	0.64	3.93	6.27	0.76	3.55	1.37	0.62	1.81	0.69	4.22	3.51
GH08	05-10	0.27	12.45	6.52	6.07	9.98	13.71	10.41	7.12	0.79	4.05	6.51	1.24	3.67	1.32	0.55	1.86	0.69	4.32	3.68
GH08	10-15	0.28	11.62	6.73	6.35	9.78	13.76	10.60	7.06	0.97	4.10	6.78	1.88	3.69	1.12	0.47	1.76	0.78	4.75	3.74
GH08	30-35	0.23	13.09	5.93	6.42	10.98	14.75	10.12	7.07	0.00	4.22	6.83	1.70	3.70	1.58	0.96	1.45	0.81	4.62	3.24

Table 12a: Mole % of the amino acids in the sediments of transect 1 in the rainy season.

Station	Depth (cm)	TAU	ASP	THR	SER	GLU	GLY	ALA	VAL	MET	ILE	LEU	TYR	PHE	b-ALA	g-ABA	HIS	ORN	LYS	ARG
GH01	00-05	0.40	13.21	5.87	5.93	12.63	13.95	10.31	6.40	0.53	3.90	5.98	0.97	3.33	2.20	1.76	1.60	0.94	4.10	3.24
GH01	05-10	0.42	13.34	5.64	5.78	13.03	14.01	10.33	6.21	0.46	3.71	5.67	0.76	3.17	2.62	2.13	1.51	1.02	4.17	3.12
GH01	10-15	0.43	13.76	5.50	5.60	13.03	14.17	10.17	6.10	0.00	3.63	5.47	0.62	3.05	2.95	2.44	1.42	1.10	4.38	2.93
GH01	30-35	0.46	14.07	5.27	5.18	13.06	14.28	9.56	6.15	0.00	3.41	4.98	0.37	2.18	3.72	2.91	1.31	1.28	4.85	2.63
GH02	00-05	0.27	12.55	6.02	6.59	12.18	13.81	10.45	6.90	0.94	4.29	7.05	1.77	3.76	1.35	0.90	1.60	0.65	3.78	3.56
GH02	05-10	0.26	14.92	6.98	7.36	0.75	15.92	11.56	7.56	0.78	4.60	7.48	1.43	4.00	1.82	1.24	1.73	0.84	4.70	3.86
GH02	10-15	0.40	13.15	5.75	6.14	12.93	13.78	10.07	6.29	0.43	3.75	5.88	0.73	3.23	2.27	1.83	1.77	0.97	4.24	3.24
GH02	30-35	0.40	13.67	5.74	5.74	12.84	13.94	10.21	6.33	0.40	3.72	5.62	0.57	3.12	2.60	2.12	1.65	1.03	4.14	2.92
GH03	00-05	0.43	12.41	5.81	6.30	11.27	14.25	9.89	6.78	1.04	4.47	6.87	1.83	3.76	1.58	1.12	1.70	0.90	4.17	3.39
GH03	05-10	0.23	12.96	6.13	6.65	11.46	14.36	10.05	6.86	0.83	4.46	7.05	1.43	3.70	1.31	0.87	1.68	0.77	4.19	3.29
GH03	10-15	0.44	13.08	5.93	6.29	11.36	13.97	9.86	6.54	1.06	4.29	6.45	1.65	3.57	1.88	1.36	1.61	0.95	4.31	3.19
GH03	30-35	0.45	13.58	5.80	5.97	11.32	13.71	9.90	6.68	0.90	4.22	6.20	1.66	3.52	2.30	1.73	1.57	1.07	4.24	2.83
GH04	00-05	0.35	13.23	6.02	6.43	11.91	14.27	10.12	6.43	0.89	4.02	6.25	1.33	3.46	1.85	1.42	1.43	0.90	4.29	3.22
GH04	05-10	0.30	13.12	5.90	6.23	12.58	14.49	10.32	6.36	0.57	3.94	6.25	0.90	3.33	2.07	1.59	1.37	0.86	4.10	3.28
GH04	10-15	0.38	13.38	5.85	5.87	12.49	14.44	10.10	6.24	0.41	3.71	5.63	0.63	3.11	2.65	2.11	1.36	1.03	4.57	3.08
GH04	30-35	0.51	14.04	5.27	5.21	13.14	14.43	9.93	6.12	0.00	3.48	5.12	0.33	2.64	3.39	2.73	1.33	1.25	4.80	2.79

w

Table 12b: Mole % of the amino acids in the sediments of transect 1 in the rainy season (*cont.*).

Station	Depth (cm)	Tau	Asp	Thr	Ser	Glu	Gly	Ala	Val	Met	Ile	Leu	Tyr	Phe	b-Ala	g-Aba	His	Orn	Lys	Arg
GH05	00-05	0.37	12.92	6.01	6.55	11.64	14.14	9.83	6.70	0.64	4.21	6.46	1.02	3.58	1.43	1.04	1.76	0.79	4.43	3.57
GH05	05-10	0.32	13.15	5.79	6.44	11.62	15.56	9.61	6.39	0.77	4.00	6.17	1.29	3.45	1.55	1.09	1.68	0.76	4.46	3.40
GH05	10-15	0.57	12.92	5.55	5.95	11.61	14.59	9.63	6.36	0.90	3.99	6.01	1.02	3.43	2.06	1.44	1.84	1.09	4.45	3.34
GH05	30-35	0.38	13.61	5.59	5.73	12.66	14.20	9.80	6.18	0.42	3.73	5.63	0.54	3.06	2.68	2.16	1.50	1.02	4.42	3.05
GH06	00-05	0.50	13.64	5.26	5.45	12.27	14.14	9.48	6.17	0.58	3.64	5.29	0.70	2.96	3.28	2.46	1.52	1.21	4.65	2.86
GH06	05-10	0.50	13.56	5.34	5.50	12.04	13.84	9.63	6.33	0.59	3.79	5.50	0.79	3.06	3.21	2.41	1.57	1.17	4.57	2.83
GH06	10-15	0.46	13.97	5.52	5.72	12.07	14.19	9.81	6.04	0.72	3.65	5.51	0.93	3.06	3.04	2.06	1.52	1.21	4.40	2.69
GH06	30-35	0.51	13.34	5.73	5.98	11.15	13.90	9.79	6.50	1.12	4.11	6.33	1.84	3.62	2.16	1.51	1.78	1.14	4.10	2.92
GH07	00-05	0.43	13.30	6.16	6.40	11.22	13.99	9.98	6.20	0.94	3.89	5.95	1.85	3.41	1.96	1.36	1.64	0.97	4.68	3.37
GH07	05-10	0.38	13.50	6.23	6.56	11.17	14.08	10.00	6.24	0.89	3.91	6.01	1.86	3.41	1.85	1.26	1.57	0.90	4.70	3.30
GH07	10-15	0.34	13.74	6.29	6.67	11.26	14.32	9.98	6.22	0.62	3.85	5.89	1.93	3.34	1.75	1.21	1.58	0.85	4.68	3.24
GH07	30-35	0.56	13.22	5.70	5.78	10.69	14.23	9.59	6.31	0.89	3.96	5.79	1.91	3.41	2.37	1.60	1.74	1.17	4.69	3.00
GH08	00-05	0.24	12.16	6.81	6.54	10.20	14.06	10.43	6.88	0.67	4.05	6.55	1.43	3.61	1.16	0.69	1.62	0.78	4.73	3.78
GH08	05-10	0.25	11.72	6.76	6.48	9.84	14.18	10.47	6.82	0.80	3.98	6.53	1.75	3.67	1.13	0.59	1.71	0.83	4.60	3.72
GH08	10-15	0.28	12.86	6.56	6.26	10.53	13.95	10.30	6.65	0.84	3.91	6.40	1.64	3.57	1.13	0.59	1.74	0.84	4.46	3.56
GH08	30-35	0.31	12.95	6.22	6.44	10.54	14.79	9.49	6.73	0.00	3.81	6.04	1.74	3.46	1.32	0.75	2.05	0.99	4.41	3.46

Table 13a: Mole % of the amino acids in the sediments of transect 2 in the dry season.

Station	Depth (cm)	Tau	Asp	Thr	Ser	Glu	Gly	Ala	Val	Met	Ile	Leu	Tyr	Phe	b-Ala	g-Aba	His	Orn	Lys	Arg
GH01	00-05	0.35	13.38	5.75	6.11	12.63	14.34	10.38	6.37	0.00	3.78	6.16	1.02	3.40	2.13	1.59	1.44	1.02	4.05	3.36
GH01	05-10	0.36	13.17	5.68	5.98	12.79	14.52	10.55	6.29	0.00	3.68	5.97	0.78	3.31	2.23	1.68	1.49	1.08	4.09	3.30
GH01	10-15	0.41	13.39	5.54	5.63	12.91	14.48	10.40	6.18	0.00	3.55	5.62	0.59	3.14	2.64	2.03	1.51	1.19	4.24	3.09
GH01	30-35	0.43	14.28	5.08	5.04	13.48	14.38	9.94	5.87	0.00	3.24	4.86	0.41	2.54	3.48	2.59	1.42	1.39	4.72	2.68
GH02	00-05	0.25	13.76	6.07	6.54	12.64	13.33	10.44	6.79	0.00	4.00	6.71	1.14	3.54	1.59	1.20	1.51	0.83	3.72	3.31
GH02	05-10	0.32	14.37	5.67	5.79	13.34	13.84	10.26	6.23	0.00	3.48	5.53	0.46	3.02	2.45	1.81	1.56	1.10	4.30	2.93
GH02	10-15	0.45	13.84	5.13	5.25	13.61	14.20	10.21	6.01	0.00	3.32	5.16	0.44	2.77	3.13	2.25	1.50	1.29	4.57	2.88
GH02	30-35	0.41	13.85	5.57	5.55	13.09	14.35	10.36	6.12	0.00	3.44	5.40	0.41	2.61	2.89	2.05	1.45	1.25	4.41	2.94
GH03	00-05	0.36	13.01	5.90	6.35	11.62	14.45	10.12	6.57	0.60	3.94	6.32	1.27	3.50	1.92	1.33	1.55	0.98	4.24	3.20
GH03	05-10	0.36	13.73	5.93	6.22	11.61	14.46	10.04	6.47	0.00	3.84	5.96	1.32	3.36	2.04	1.52	1.55	1.05	4.49	3.11
GH03	10-15	0.39	13.90	5.72	6.07	11.84	14.70	10.06	6.38	0.00	3.78	5.78	1.49	3.24	2.43	1.77	1.47	1.10	4.32	2.95
GH03	30-35	0.39	13.92	5.72	6.09	11.58	14.43	10.17	6.68	0.00	3.99	6.29	1.66	3.52	2.01	1.51	1.47	1.08	4.05	2.86
GH04	00-05	0.36	12.51	5.83	6.19	12.15	14.51	10.45	6.56	0.58	3.88	6.23	0.92	3.41	2.12	1.52	1.43	1.03	4.16	3.33
GH04	05-10	0.39	13.48	5.77	5.75	12.69	14.44	10.51	6.32	0.00	3.57	5.62	0.61	3.11	2.55	1.89	1.50	1.13	4.35	3.09
GH04	10-15	0.38	13.83	5.64	5.65	13.26	14.47	10.43	6.10	0.00	3.46	5.40	0.49	3.00	2.59	1.99	1.39	1.14	4.24	3.07
GH04	30-35	0.47	14.03	5.42	5.33	13.18	14.10	10.30	6.07	0.00	3.41	5.20	0.54	2.92	2.98	2.25	1.47	1.39	4.45	2.88

y

Table 13b: Mole % of the amino acids in the sediments of transect 2 in the dry season (*cont.*).

Station	Depth (cm)	Tau	Asp	Thr	Ser	Glu	Gly	Ala	Val	Met	Ile	Leu	Tyr	Phe	b-Ala	g-Aba	His	Orn	Lys	Arg
GH05	00-05	0.40	13.29	5.59	6.16	12.06	15.11	9.84	6.44	0.00	3.75	5.86	0.84	3.30	2.08	1.32	1.66	1.03	4.46	3.37
GH05	05-10	0.35	13.56	5.58	6.07	12.47	15.17	9.89	6.38	0.00	3.69	5.76	0.72	3.19	1.99	1.44	1.57	0.95	4.37	3.29
GH05	10-15	0.40	13.74	5.51	5.72	13.05	14.47	10.11	6.16	0.00	3.54	5.59	0.58	3.11	2.43	1.84	1.51	1.10	4.31	3.15
GH05	30-35	0.41	14.38	5.34	5.32	13.27	13.97	10.22	6.12	0.00	3.49	5.29	0.48	2.93	2.94	2.34	1.43	1.20	4.34	2.89
GH06	00-05	0.42	13.74	5.58	5.82	11.80	14.40	9.96	6.66	0.00	3.96	6.09	1.09	3.42	2.29	1.73	1.43	1.02	4.30	2.94
GH06	05-10	0.40	13.69	5.73	6.07	11.55	14.22	10.08	6.66	0.00	3.95	6.21	1.50	3.47	2.11	1.47	1.58	1.02	4.37	3.00
GH06	10-15	0.40	13.81	5.74	5.94	11.45	14.18	10.02	6.74	0.00	4.00	6.24	1.70	3.52	2.01	1.48	1.69	1.11	4.31	2.94
GH06	30-35	0.43	14.03	5.67	5.81	11.38	14.48	9.97	6.67	0.00	3.76	5.93	1.75	3.53	2.07	1.47	1.56	1.19	4.56	3.00
GH07	00-05	0.31	13.50	6.18	6.54	11.49	14.32	10.18	6.63	0.00	3.92	6.01	1.49	3.42	1.80	1.36	1.31	0.90	4.89	3.36
GH07	05-10	0.32	13.70	6.16	6.46	11.31	14.35	10.11	6.61	0.00	3.89	5.94	1.40	3.35	1.87	1.38	1.46	0.85	4.80	3.32
GH07	10-15	0.36	13.65	5.92	6.35	11.22	14.59	9.95	6.69	0.00	3.97	6.05	1.50	3.44	1.88	1.44	1.33	1.02	4.72	3.19
GH07	30-35	0.41	13.82	5.64	5.56	10.92	14.82	9.73	6.43	0.73	3.80	5.56	1.63	3.29	2.39	1.64	1.47	1.07	4.72	2.96
GH08	00-05	0.23	13.46	6.00	5.40	10.54	13.82	10.16	6.80	0.00	3.89	6.19	0.47	3.49	1.52	0.70	1.48	0.61	4.08	3.59
GH08	05-10	0.28	13.42	5.93	5.28	10.54	13.72	10.05	6.98	0.00	3.96	6.21	0.48	3.47	1.63	0.79	1.54	0.66	4.01	3.81
GH08	10-15	0.26	13.12	6.12	5.75	10.63	14.12	10.18	6.86	0.57	3.95	6.36	0.95	3.61	1.44	0.64	1.59	0.64	4.17	3.70
GH08	30-35	0.28	12.95	5.71	6.39	11.03	14.55	9.85	7.45	0.00	4.41	7.21	1.56	3.93	1.29	0.71	1.39	0.70	4.31	3.42

Table 14a: Mole % of the amino acids in the sediments of transect 2 in the rainy season.

Station	Depth (cm)	Tau	Asp	Thr	Ser	Glu	Gly	Ala	Val	Met	Ile	Leu	Tyr	Phe	b-Ala	g-Aba	His	Orn	Lys	Arg
GH01	00-05	0.29	13.33	5.86	5.94	12.62	14.48	10.46	6.28	0.31	3.67	5.80	0.60	3.12	2.58	1.85	1.51	1.08	4.29	3.10
GH01	05-10	0.32	13.69	5.75	5.66	13.12	14.28	10.47	6.10	0.32	3.53	5.49	0.42	2.98	2.75	2.08	1.52	1.15	4.33	3.08
GH01	10-15	0.32	13.72	5.71	5.60	12.82	14.35	10.56	6.21	0.00	3.55	5.52	0.41	2.98	2.93	2.20	1.54	1.16	4.43	2.95
GH01	30-35	0.32	14.06	5.58	5.41	12.64	14.55	10.11	6.27	0.30	3.45	5.21	0.44	2.78	3.42	2.46	1.40	1.29	4.65	2.64
GH02	00-05	0.28	12.85	6.02	6.60	12.55	13.41	10.44	6.67	0.82	4.20	7.09	1.53	3.73	1.60	1.12	1.36	0.73	3.54	3.48
GH02	05-10	0.28	13.27	6.01	6.25	12.69	13.87	9.98	6.44	0.31	3.76	6.14	0.63	3.28	2.29	1.69	1.58	0.98	4.32	3.19
GH02	10-15	0.40	13.62	5.55	5.84	13.06	13.72	9.98	6.11	0.43	3.62	5.65	0.64	3.10	2.65	2.06	1.32	1.08	4.54	3.03
GH02	30-35	0.43	13.84	5.74	5.72	12.75	13.95	10.03	6.14	0.00	3.61	5.44	0.47	2.87	3.18	2.32	1.04	1.13	4.68	2.83
GH03	00-05	0.24	13.01	6.18	6.64	11.86	14.24	10.29	6.69	0.65	4.16	6.94	1.42	3.64	1.54	0.93	1.57	0.80	3.93	3.31
GH03	05-10	0.23	13.34	6.18	6.61	12.10	14.26	10.08	6.63	0.51	4.07	6.72	1.03	3.55	1.56	1.08	1.53	0.85	4.05	3.28
GH03	10-15	0.27	13.77	6.12	6.25	12.15	14.30	9.91	6.37	0.37	3.77	6.01	0.66	3.24	2.11	1.49	1.58	1.01	4.56	3.07
GH03	30-35	0.35	14.03	5.48	5.11	11.44	14.28	9.64	7.00	0.56	4.20	5.80	1.35	3.21	2.85	2.29	1.47	1.20	4.56	2.62
GH04	00-05	0.27	13.15	6.08	6.41	12.16	14.45	10.14	6.50	0.40	3.84	6.29	0.83	3.37	2.08	1.28	1.65	0.97	4.21	3.19
GH04	05-10	0.22	12.99	6.26	6.65	11.92	14.43	10.31	6.62	0.49	3.98	6.66	0.83	3.51	1.83	1.16	1.55	0.88	4.27	3.22
GH04	10-15	0.27	13.75	5.98	6.01	12.62	14.39	10.52	6.15	0.27	3.53	5.69	0.47	3.05	2.55	1.73	1.53	1.05	4.46	3.04
GH04	30-35	0.32	14.14	5.68	5.49	12.86	14.37	10.21	6.12	0.28	3.39	5.26	0.33	2.83	3.11	2.21	1.52	1.25	4.58	2.77

Table 14b: Mole % of the amino acids in the sediments of transect 2 in the rainy season (*cont.*).

Station	Depth (cm)	Tau	Asp	Thr	Ser	Glu	Gly	Ala	Val	Met	Ile	Leu	Tyr	Phe	b-Ala	g-Aba	His	Orn	Lys	Arg
GH05	00-05	0.31	13.36	6.14	6.74	12.05	14.91	9.90	6.30	0.51	3.88	6.17	0.96	3.39	1.75	1.15	1.22	0.80	4.50	3.32
GH05	05-10	0.41	12.63	5.77	5.83	11.85	14.35	9.78	6.70	0.50	4.17	6.02	0.82	3.33	2.09	1.68	1.13	0.98	4.96	3.35
GH05	10-15	0.38	13.66	5.64	5.38	12.63	13.98	9.86	6.63	0.41	4.07	5.84	0.66	3.19	2.50	2.21	0.98	0.95	4.59	3.09
GH05	30-35	0.46	13.70	5.60	5.25	12.57	13.71	9.68	6.47	0.51	3.99	5.63	0.65	3.15	2.98	2.62	0.82	1.14	4.61	2.96
GH06	00-05	0.36	13.99	5.82	5.53	11.43	14.37	9.77	6.70	0.83	4.25	5.82	1.55	3.27	2.35	1.93	0.95	1.01	5.06	2.94
GH06	05-10	0.47	13.65	5.76	5.50	11.30	14.21	9.74	6.52	0.92	4.24	5.74	1.68	3.31	2.58	2.13	0.86	1.15	4.93	2.94
GH06	10-15	0.56	13.33	5.67	5.62	11.15	13.74	9.58	6.69	0.88	4.37	5.99	1.82	3.44	2.46	1.99	0.89	1.28	4.93	3.05
GH06	30-35	0.52	13.70	5.58	5.24	11.18	14.22	9.61	6.65	0.92	4.35	5.78	1.76	3.35	2.67	2.22	0.84	1.23	5.03	2.86
GH07	00-05	0.39	13.20	6.46	6.64	11.07	14.09	10.04	6.39	0.89	4.04	6.12	1.83	3.45	1.81	1.35	1.09	0.62	5.01	3.37
GH07	05-10	0.36	13.47	6.44	6.70	11.13	14.16	10.05	6.36	0.72	3.99	6.01	1.91	3.40	1.75	1.24	1.07	0.92	4.88	3.26
GH07	10-15	0.35	13.52	6.47	6.73	11.19	14.24	10.08	6.43	0.62	4.02	6.11	1.87	3.43	1.72	1.23	1.07	0.64	4.88	3.29
GH07	30-35	0.44	13.45	6.36	6.84	10.00	13.81	9.25	6.49	0.90	4.01	6.05	1.82	3.53	1.88	0.96	1.22	1.03	4.69	2.95
GH08	00-05	0.27	11.11	7.01	6.80	9.87	14.32	10.79	7.08	0.81	4.17	6.79	1.64	3.76	1.15	0.71	1.78	0.80	5.02	3.94
GH08	05-10	0.36	12.13	6.83	6.66	10.68	13.53	9.80	6.75	0.91	4.17	6.60	1.75	3.72	1.23	0.79	1.17	0.82	4.74	3.78
GH08	10-15	0.30	12.68	6.72	6.40	10.57	14.29	10.47	6.83	0.87	3.95	6.46	1.91	3.63	1.14	0.63	1.85	0.90	4.57	3.74
GH08	30-35	0.49	12.90	6.53	6.25	10.40	14.01	9.76	6.46	1.08	4.15	6.16	2.26	3.53	1.42	0.88	1.17	1.08	4.72	3.38

Table 15: Mole % of amino acids in the plant materials in the dry season.

Station	Plant	MOLE %	Tau		Asp		Thr		Ser		Glu		Gly		Ala		Val		Met		Ile	
			trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2
GH01	*Sesuvium*	stem	0.36	0.23	9.97	9.99	5.07	5.28	6.40	7.36	15.44	13.27	10.88	11.54	9.99	10.52	7.19	7.29	0.68	0.57	4.40	4.33
GH01	*Sesuvium*	leaf	0.29	0.23	10.12	10.05	5.08	5.19	7.01	6.88	13.15	12.41	12.90	13.02	9.43	10.17	6.51	6.89	1.14	0.47	4.41	4.60
GH02	*Sesuvium*	stem	0.39	0.28	10.55	9.43	4.86	4.78	6.98	6.13	19.01	18.03	10.20	10.62	9.57	9.82	6.59	7.34	0.00	0.00	3.74	4.39
GH02	*Sesuvium*	leaf	0.29	0.25	9.98	10.07	5.01	5.13	6.46	6.90	13.81	14.12	12.69	12.49	9.44	9.62	7.27	6.70	0.00	1.24	4.89	4.53
GH02	*Avicennia*	leaf	0.31	0.24	11.13	10.94	5.95	5.95	6.50	6.97	11.26	11.36	12.07	12.51	9.75	9.94	7.92	7.44	0.53	0.48	5.45	5.04
GH04	*Lumnitzera*	leaf	0.20	0.30	10.34	10.25	5.53	5.44	6.75	6.62	11.49	12.28	11.88	11.78	9.49	9.35	7.04	7.09	0.42	0.00	4.92	4.91
GH05	*Lumnitzera*	leaf	0.19	0.19	10.90	10.74	6.01	5.36	6.73	5.95	11.07	10.83	11.41	11.66	9.77	9.42	7.12	7.72	0.37	0.00	5.10	5.52
GH05	*Avicennia*	leaf		0.29		11.57		6.20		7.00		11.64		11.79		9.90		7.46		0.47		4.97
GH06	*Avicennia*	leaf	0.24	0.23	10.97	11.43	5.82	5.79	6.16	6.32	11.51	11.43	11.91	11.96	9.96	9.67	8.03	7.71	0.40	0.53	5.47	5.33

Station	Plant	MOLE %	Leu		Tyr		Phe		b-Ala		g-Aba		His		Orn		Lys		Arg	
			trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2
GH01	*Sesuvium*	stem	6.67	7.52	3.09	3.18	3.77	4.00	0.42	0.33	1.28	1.35	2.26	2.66	0.45	0.00	4.44	4.55	5.55	4.30
GH01	*Sesuvium*	leaf	7.61	8.23	3.06	2.60	4.16	4.33	0.36	0.32	0.95	1.31	2.38	2.40	0.00	0.00	4.32	4.66	5.97	4.74
GH02	*Sesuvium*	stem	6.20	6.72	2.96	2.36	3.57	3.70	0.47	0.47	1.67	1.72	2.63	2.51	0.00	0.47	4.17	4.22	4.26	4.08
GH02	*Sesuvium*	leaf	7.84	8.11	1.72	3.06	4.22	4.36	0.41	0.33	1.39	1.00	2.35	2.30	0.56	0.00	4.39	4.01	4.86	4.51
GH02	*Avicennia*	leaf	9.49	9.93	2.70	2.66	4.61	4.70	0.29	0.30	0.45	0.44	1.69	1.88	0.00	0.36	3.68	3.33	4.52	4.40
GH04	*Lumnitzera*	leaf	9.21	9.04	3.16	2.85	4.85	4.81	0.27	0.40	0.46	0.73	2.52	2.62	0.27	0.00	4.94	4.74	5.10	4.99
GH05	*Lumnitzera*	leaf	9.52	9.61	2.97	2.96	5.02	5.11	0.24	0.31	0.33	0.47	2.34	2.47	0.27	0.00	4.70	5.12	4.73	4.86
GH05	*Avicennia*	leaf		9.70		2.85		4.79		0.32		0.74		1.65		0.00		3.13		4.29
GH06	*Avicennia*	leaf	9.79	9.58	2.80	3.07	4.75	4.71	0.28	0.43	0.82	0.77	1.71	1.65	0.26	0.23	3.86	3.65	4.46	4.59

cc

Table 16: Mole % of amino acids in the plant materials in the rainy season.

Station	Plant	MOLE %	Tau		Asp		Thr		Ser		Glu		Gly		Ala		Val		Met		Ile	
			trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2
GH01	*Sesuvium*	stem	0.15	0.18	9.24	9.25	5.00	4.80	6.77	6.73	18.74	20.73	9.25	9.64	11.21	10.87	6.22	5.94	1.01	0.73	3.83	3.70
GH01	*Sesuvium*	leaf	0.38	0.39	10.13	10.12	5.48	5.47	6.44	6.43	14.15	14.39	10.54	10.49	9.96	10.06	6.39	6.28	1.26	1.41	4.49	4.45
GH02	*Sesuvium*	stem	0.21	0.41	9.04	9.11	4.74	4.90	6.49	6.55	25.12	22.81	8.28	8.43	9.87	10.11	5.82	5.89	0.60	1.21	3.37	3.82
GH02	*Sesuvium*	leaf	0.29	0.42	10.87	10.32	5.38	5.41	6.73	6.88	15.27	16.02	10.37	10.64	9.62	9.83	6.21	6.19	1.24	0.79	4.44	4.43
GH02	*Avicennia*	leaf	0.23	0.17	11.65	11.38	6.20	6.15	7.23	7.19	11.37	11.42	12.15	11.99	9.82	9.82	7.22	7.31	0.90	0.50	5.02	5.17
GH04	*Lumnitzera*	leaf	0.34	0.34	10.38	10.13	5.92	5.87	6.50	6.37	11.70	11.77	10.69	10.57	9.36	9.37	6.92	6.95	0.70	1.00	5.02	5.07
GH05	*Lumnitzera*	leaf	0.17	0.14	10.04	10.16	5.71	5.78	6.46	6.52	11.35	11.54	10.79	10.64	10.01	9.86	7.03	7.05	0.50	0.45	5.04	5.07
GH05	*Avicennia*	leaf		0.35		11.18		6.30		7.15		11.52		11.07		9.74		7.18		1.07		4.99
GH06	*Avicennia*	leaf	0.38	0.42	11.14	11.09	6.31	6.33	7.04	7.03	11.38	11.63	10.84	10.84	9.70	9.74	7.03	7.04	1.05	1.03	4.90	4.88

Station	Plant	MOLE %	Leu		Tyr		Phe		b-Ala		g-Aba		His		Orn		Lys		Arg	
			trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2	trs. 1	trs. 2
GH01	*Sesuvium*	stem	6.38	6.15	2.92	2.76	3.36	3.33	0.32	0.38	1.14	1.14	2.24	2.23	0.33	0.43	4.97	4.65	4.22	4.28
GH01	*Sesuvium*	leaf	7.79	7.74	3.22	3.20	4.24	4.18	0.48	0.49	0.97	1.05	1.84	1.82	0.71	0.67	5.18	4.97	4.84	4.81
GH02	*Sesuvium*	stem	5.35	5.85	2.63	2.97	3.04	3.39	0.42	0.53	1.35	1.32	2.45	1.70	0.57	0.71	4.52	4.49	4.27	4.08
GH02	*Sesuvium*	leaf	7.67	7.40	2.98	2.95	4.23	4.15	0.42	0.51	0.87	1.04	1.86	1.63	0.52	0.79	5.11	4.79	4.76	4.42
GH02	*Avicennia*	leaf	9.52	9.63	2.44	2.82	4.65	4.66	0.44	0.39	0.50	0.52	1.83	1.67	0.46	0.35	3.05	3.11	3.73	4.23
GH04	*Lumnitzera*	leaf	9.25	9.32	2.98	3.10	4.75	4.82	0.40	0.39	0.93	0.93	2.03	1.98	0.57	0.46	5.50	5.41	4.90	5.04
GH05	*Lumnitzera*	leaf	9.73	9.91	3.00	3.02	4.91	4.98	0.23	0.18	0.98	0.78	2.19	2.20	0.00	0.27	5.55	5.53	4.67	4.82
GH05	*Avicennia*	leaf		9.54		2.86		4.70		0.31		1.50		1.23		0.56		3.15		4.20
GH06	*Avicennia*	leaf	9.41	9.40	3.00	2.88	4.67	4.64	0.34	0.35	1.88	1.86	1.27	1.26	0.57	0.62	3.41	3.36	4.35	4.19

dd

ee