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## Manuscript Details

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### Abstract

A 1500-year record of mangrove dynamics has been established from palaeoecological analyses on three cores from Salak Phet Bay, Koh Chang island in the eastern Gulf of Thailand. The occurrence of *Rhizophora*, accompanied by other mangrove species, suggested that Salak Phet Bay supported a mangrove community from at least 1500 cal yr BP. From 1500 cal yr BP the mangrove extent decreased indicating less inundation frequency, possibly in response to a sea-level fall until 1300 cal yr BP. Following this regression, sea-level rise resulted in an increased presence of mangrove taxa until 500 cal yr BP. The study documents that Salak Phet Bay was characterised by relatively low saline conditions based on the occurrence of the moist-loving species (*Oncosperma*) around 1500-500 cal yr BP. After 500 cal yr BP mangrove taxa gradually decreased and terrestrial herbaceous taxa, mainly grasses, increased suggesting that the frequency of marine inundation was reduced as sea level fell. Drier conditions were also recorded by an increase in terrestrial grasses and a decrease in *Oncosperma* after 500 cal yr BP. In the uppermost sediments the increased presence of *Rhizophora* is probably associated with recent global sea-level rise although changes in mangrove composition are possibly related to human activities within Koh Chang. The sedimentation rate and the mangrove migration at Koh Chang have kept pace over the past 1500 years but this may be challenged under predicted future rapid sea-level rise as accommodation space for mangroves to migrate inland is required to maintain viable mangrove forests.

|   |   |
|---|---|
| <b>Keywords</b>                           | pollen analysis, palaeoecological analysis, the eastern Gulf of Thailand, sea-level change                    |
| <b>Corresponding Author</b>               | Paramita Punwong  |
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| <b>Suggested reviewers</b>                | Joanna Ellison  |

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fig 3.zonation and stra-shell-1.tif [Figure]  
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## Cover letter

The manuscript is a Research Paper detailing late Holocene mangrove dynamics and palaeoenvironment recorded from an island of the eastern Gulf of Thailand using palaeoecological analyses. We presently know little about the vegetation history of this area and this research allows us to establish a better understanding of sea level changes, climate history and human activity on the ecosystem across this region.

## **Response to reviewer**

Comments from the editors and reviewers:

### **Editor**

Thank you for submitting your manuscript to Quaternary International. The reviewer noticed a few typo's. Please have an extra close look and submit the final version.

- We have looked through the manuscript and corrected typo errors.

### **Reviewer 2**

I commend the authors on the efforts they have made to the manuscript. With the clarity on limitations on surveyed elevations and the revised figures and text I recommend that this paper be accepted for QI.

1 **Mangrove dynamics and environmental changes on Koh Chang, Thailand during the**  
2 **last millennium**

3

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17 **Abstract**

18 A 1500-year record of mangrove dynamics has been established from  
19 palaeoecological analyses on three cores from Salak Phet Bay, Koh Chang island in the  
20 eastern Gulf of Thailand. The occurrence of *Rhizophora*, accompanied by other mangrove  
21 species, suggested that Salak Phet Bay supported a mangrove community from at least 1500  
22 cal yr BP. From 1500 cal yr BP the mangrove extent decreased indicating less inundation  
23 frequency, possibly in response to a sea-level fall until 1300 cal yr BP. Following this  
24 regression, sea-level rise resulted in an increased presence of mangrove taxa until 500 cal yr  
25 BP. The study documents that Salak Phet Bay was characterised by relatively low saline  
26 conditions based on the occurrence of the moist-loving species (*Oncosperma*) around 1500-  
27 500 cal yr BP. After 500 cal yr BP mangrove taxa gradually decreased and terrestrial  
28 herbaceous taxa, mainly grasses, increased suggesting that the frequency of marine  
29 inundation was reduced as sea level fell. Drier conditions were also recorded by an increase  
30 in terrestrial grasses and a decrease in *Oncosperma* after 500 cal yr BP. In the uppermost  
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33 activities within Koh Chang. The sedimentation rate and the mangrove migration at Koh

34 Chang have kept pace over the past 1500 years but this may be challenged under predicted  
35 future rapid sea-level rise as accommodation space for mangroves to migrate inland is  
36 required to maintain viable mangrove forests.

37

38 **Keywords:** pollen analysis, palaeoecological analysis, the eastern Gulf of Thailand, sea-level  
39 change

40

## 41 **1. Introduction**

42 Mangroves are assemblages of trees and shrubs that have developed physiological and  
43 morphological adaptations to the intertidal habitat. Mangroves are found between mean sea  
44 level and high water spring tide along subtropical to tropical coasts (Woodroffe & Grindrod,  
45 1991; Ellison, 2008; Punwong et al., 2013a). Mangroves provide vital ecosystem services  
46 such as coastal protection, habitats for animals and plants, leading to high biodiversity,  
47 filtering of sediment and pollution and regulation of the global carbon budget (Spalding et al.,  
48 2010; Marchio et al., 2016). Mangrove species normally grow in bands parallel to the  
49 shoreline related to the influence of ecological and environmental factors such as salinity,  
50 tides, muddy sediments and anaerobic soils (Kathiresan and Bingham, 2001).

51 Mangrove ecosystems are highly sensitive to climate changes, including the amount  
52 of precipitation, sea-level changes and human disturbances (Gilman et al., 2008). Changes in  
53 regional rainfall pattern affect freshwater runoff which in turn influences salinity, leading to  
54 changes in the mangrove composition (Snedaker, 1995; Ellison, 2000; Gilman et al., 2008;  
55 Mikhailov and Isupova, 2008). Sea level change causes changes in tidal inundation frequency  
56 and magnitude, and is one of the most significant factors influencing mangrove composition  
57 and distribution. Mangroves respond to sea-level fluctuations by migrating landward or  
58 seaward with a rise or a fall in sea level, respectively; hence are considered a sensitive  
59 indicator of sea-level and tidal regime (Gilman et al., 2008; Walters et al., 2008). Mangroves  
60 can tolerate sea-level rises if the rate of mangrove sedimentation is equal to, or more than, the  
61 rate of sea-level rise. If the mangrove sedimentation rate is less than the rate of sea-level rise  
62 then the mangrove communities will experience die back. If sea level rises and the coastal  
63 zone lacks accommodation space for landward mangrove migration due to factors such as  
64 steep topography and/or recent coastal development, the mangrove ecosystem will die *in situ*  
65 (Gilman et al., 2008). Mangroves accumulate sediment on small islands more slowly than in  
66 riverine mangrove forests on the mainland as they are primarily influenced by tides with low  
67 freshwater sediment input (Twilley, 1992; Ellison, 2000). Therefore, mangroves on small

68 islands are less likely to survive under sea-level rise (Ellison, 2000). Recently, studies  
69 evaluating the ability of mangroves to cope with sea-level rise, by establishing past mangrove  
70 sedimentation rates have been increasing (Ellison, 2000; González et al., 2010; Urrego, 2013;  
71 Ellison, 2015; Ellison and Strickland, 2013; Setyaningsih et al., 2019). An assessment of  
72 mangrove vulnerability to future sea level rise is crucial to mitigate and plan for the effects  
73 on these ecosystems.

74 Global sea-level has risen approximately 1-2 mm a<sup>-1</sup> since the late 19th century  
75 (Church & White, 2011); this is a major threat to mangrove ecosystems (Ellison, 2015) and  
76 of great concern to populations who live within the low-lying coastal areas. Recent rapidly  
77 rising sea level across the Gulf of Thailand of between 0.7-12.7 mm a<sup>-1</sup> during AD 1942-  
78 2004 (Trisirisatayawong et al., 2011; Sojisuporn et al., 2013) indicates that Thailand has  
79 experienced a higher rate of sea-level rise than the global average over the last few decades.  
80 Pollen of mangrove taxa, recovered from the sedimentary record has been increasingly used  
81 as an indicator of past ecosystem response to sea-level change across the tropics (Behling et  
82 al., 2001; Blasco et al., 1996; Versteegh et al., 2004; Ellison, 2008; Hait et al., 2009; Punwong  
83 et al., 2013a; b; 2018a). Sea level index points can be developed by establishing an indicative  
84 range for mangrove species through contemporary studies of the altitude of the upper and  
85 lower limits of the mangrove areas (Ellison, 2005; Horton et al., 2005). A study  
86 reconstructing sea-level from East Africa demonstrated that the relationship of ratios between  
87 the key mangrove taxa and their altitudes had the potential to refine the vertical errors of sea-  
88 level change (Punwong et al., 2018a). In addition, records retrieved from mangrove sediment  
89 can be used to detect other past natural events such as storm surge (González et al., 2010).

90 Most records of Holocene sea-level change along the Gulf of Thailand indicate that  
91 sea level reached its maximum with a highstand at about 2-4 m above the present mean sea  
92 level around 6000 cal yr BP (Sinsakul, 2000; Tanabe et al., 2003; Choowong et al., 2004;  
93 Horton et al., 2005). This mid-Holocene sea-level rise is in agreement with a study from the  
94 peninsular of Malaysia and Thailand indicating a highstand between 6800-5000 cal yr BP  
95 between 5 m (Tjia, 1996) and 1.7 m (Mallinson et al., 2014) above the present mean sea  
96 level. The mid-Holocene sea-level rise is recorded slightly earlier at around 7000 cal yr BP in  
97 Singapore (Hesp et al., 1998, Bird et al., 2007). Relative sea level is then recorded to have  
98 fluctuated in the Gulf of Thailand until it reached its present level around 1500 cal yr BP  
99 (Tjia, 1996; Sinsakul, 2000; Choowong et al., 2004; Horton et al., 2005; Mallinson et al.,  
100 2014). Only one study has been undertaken directly on mangroves located in the upper Gulf  
101 of Thailand (Punwong et al., 2018b). The results demonstrated that a higher than present sea



102 level influenced the area from at least 1100 cal yr BP until 700 cal yr BP before a lower sea  
103 level occurred until around 200-100 cal yr BP. After around 100 cal yr BP, there was a signal  
104 of recent sea-level rise that corresponded to the instrumental sea-level study based on tide  
105 gauge data spanning the last 60 years (Trisirisatayawong et al., 2011).

106 To date, studies have neglected to investigate the mangrove vegetation and  
107 environmental history of the offshore islands within the Gulf of Thailand during the last  
108 millennium. In this study we report the first high-resolution record of mangrove dynamics  
109 and environmental history from Salak Phet Bay, Koh Chang island in the eastern area of the  
110 Gulf of Thailand. Palaeoecological methods and techniques including stratigraphical analysis,  
111 pollen analysis, loss on ignition and radiocarbon dating of mangrove sediments were used to  
112 investigate ecosystem and environmental change over the last 1500 years. Koh Chang has  
113 experienced extensive tourism development, associated activities (e.g. road building) and  
114 population growth (Kusanagi et al., 2003) that has potentially influenced coastal ecosystems  
115 over recent decades. The reconstruction of the coastal environmental history prior to human  
116 disturbances in this area will be compared to sea-level reconstruction available for the region  
117 to understand the capacity of mangroves in Koh Chang to adapt to current and future  
118 scenarios of climate change and provide insights into how mangroves respond to  
119 environmental changes; crucial information for the management of the coastal zone and  
120 conservation of mangrove areas.

121

## 122 **1.1. Study site**

### 123 **Location**

124 Salak Phet Bay is situated in the east of Koh Chang island, Trat Province, in the  
125 eastern region of the Gulf of Thailand (Figure 1). Koh Chang is the second largest island of  
126 Thailand and was designated as a National Park in 1982. It is influenced by a diurnal tide  
127 with a tidal range of 0.9 m as recorded at Mak island (20 km away) (Admiralty Tide Table,  
128 2014). The study area is covered by a belt of dense mangroves varying from 600 m to 1200 m  
129 in width occurring in a south-eastern alignment. The area is characterised by shallow  
130 unconnected tidal creeks that have occasional freshwater input from terrestrial runoff,  
131 particularly during the rainy season.

132

### 133 **Geology and Geomorphology**

134 Koh Chang island is composed of Permo-Triassic volcanic rock forming an igneous  
135 mountain range with cliffs and steep slopes (Songtham, 2011; Pumijumnong & Payomrat,  
136 2013). The elevation of Koh Chang ranges between mean sea level and 743 metres (Kusanagi  
137 et al., 2003; Pumijumnong & Payomrat, 2013) and the mountains of Koh Chang are formed  
138 of fine-grained volcanic rock, light-brown or red in colour (Schmidt, 1902). The plains along  
139 the east coast of the island are rich in sandy clay and the west coast consists of beach sand  
140 (Pumijumnong & Payomrat, 2013).

141

## 142 **Climate and vegetation**

143 The climate of Koh Chang is characterised by two seasons: a summer season from  
144 November to April, and a rainy season from May to October. The climate is influenced by  
145 northeast and southwest Asian monsoons; the northeast monsoon brings dry air during the  
146 summer season and damp air during the rainy season accounting for 90% of the average  
147 annual rainfall of ~4900 mm (1982-2011) (Pumijumnong & Payomrat, 2013; Sirianansakul  
148 & Pumijumnong, 2014). The average maximum, minimum, and mean temperatures are 31.8  
149 °C, 23.6 °C, and 27.4 °C, respectively (Thai Meteorological Department, 2010). The  
150 vegetation on Koh Chang consists of around 1000 species (Pengkhilai et al., 2007) mainly  
151 classed as tropical rainforest taxa (Pumijumnong & Payomrat, 2013). On the east coast of  
152 Koh Chang, where Salak Phet is located, the area is covered by beach and mangrove forest.  
153 The dominant trees are *Terminalia catappa* L., *Melaleuca cajuputi* Powell, *Syzygium grande*  
154 (Wight) Walp., *S. gratum* (Wight) S. N. Mitra and *Pandanus odoratissimus* L.f. Typical  
155 mangrove taxa include *Rhizophora mucronata* Lam., *R. apiculata* Blume, *Ceriops decandra*  
156 Ding Hou, *C. tagal* (Perr.) C. B. Rob., *Bruguiera gymnorrhiza* (L.) Lam., *B. parviflora*  
157 (Roxb.) Griff., *Avicennia alba* Blume, *Xylocarpus granatum* J.Koenig, *X. moluccensis* (Lam.)  
158 M.Roem. and *Hibiscus tiliaceus* L. (Chamchumroon & Puff, 2003).

159

160 *(Insert Figure 1)*

161

## 162 **2. Materials and methods**

163

### 164 **2.1. Fieldwork and sampling**

165 Three sediment cores, SLP-S (12°00'00.7"N 102°22'47.4"E), SLP-M (12°00'04.0"N  
166 102°22'43.8"E) and SLP-L (12°00'09.1"N 102°22'38.1"E) were extracted along a transect

167 oriented from landward to seaward through the mangrove in Salak Phet Bay (Figure 1B). The  
168 SLP-S core site was located in the seaward area, SLP-M core site in the middle of the  
169 mangrove area about 150 m from SLP-S and SLP-L core site was located in the landward  
170 area of the mangrove ecosystem approximately 240 m away from SLP-M. A 50 cm long, 5  
171 cm diameter Russian corer was used to extract the cores samples from overlapping boreholes.  
172 Sediment samples were inserted in the sectioned PVC pipes, wrapped in aluminum foil and  
173 plastic sheeting and then labelled and packaged. A vegetation survey of 10 m<sup>2</sup> plots around  
174 the coring sites and along the transect from the landward to seaward in the mangrove area of  
175 Salak Phet was also undertaken.

176

## 177 **2.2. Palaeoecological analysis**

178 The three sediment cores, SLP-S, SLP-M and SLP-L were described in the laboratory  
179 following Tröels-Smith's classification (1955). They were subsampled at 10 cm along the  
180 whole length of each core for pollen, charcoal and loss on ignition (LOI) analyses. Pollen and  
181 spores were extracted using the acetolysis method (Erdtman, 1969; Faegri and Iversen, 1989)  
182 and heavy liquid separation with sodiumpolytungstate solution (Hunt, 1985). Exotic  
183 *Lycopodium* spores (batch 3862:  $9666 \pm 212$  grains per tablet) were used to determine the  
184 pollen concentration following Bonny (1972) and Smol et al. (2001). Sample residues were  
185 stored in silicone oil. Pollen and spores were identified by comparison with pollen from  
186 extant specimens and modern pollen references (Thanikaimoni, 1987; Chumchim, 2010;  
187 Hutangkura, 2012). *Bruguiera gymnorhiza* and *Ceriops tegal* were grouped together as  
188 *Bruguiera/Ceriops* type because they could not be distinguished by light microscopy  
189 (Chappell & Grindrod, 1985). The pollen content of some samples was very sparse and  
190 therefore insufficient to achieve a count of 300 grains. To determine the optimal grain count,  
191 the number of pollen taxa in five samples from each site were counted and recorded for every  
192 20 grains. After 80 grains the number of new taxa did not increase. At least 150 pollen grains  
193 were counted for each level after establishing that this number was sufficient to identify any  
194 new taxa. Pollen taxa were grouped into ecological categories to aid interpretation:  
195 mangroves, back mangroves, terrestrial herbaceous, non-mangrove arboreal and unknown.  
196 Mangroves and back mangroves were grouped according to Watson's (1928) and Santisuk's  
197 (1983) inundation classes. Pteridophyte spores were excluded from pollen sum. Pollen data  
198 were zoned using a stratigraphically constrained cluster analysis, CONISS (Grimm, 1991).  
199 Pollen-slide charcoal analysis was undertaken to reconstruct fire history using microscopic

200 charcoal. However, the charcoal fragments were extremely sparse and insufficient to be  
201 analysed. Loss on ignition (LOI) at 550°C and 950°C followed Heiri et al. (2001) was used to  
202 determine the organic carbon and carbonate content. The palaeoecological data were plotted  
203 as diagrams using TILIA2 and TILIA\*Graph (Grimm, 1991).

204

### 205 **2.3. Chronology**

206 Eight organic samples from the basal sections of the cores and where biostratigraphic  
207 changes were noted were prepared for the acid-base-acid (ABA) pre-treatment method  
208 following Brock et al. (2010). The samples were radiocarbon dated by Acceleration Mass  
209 Spectrophotometry (AMS) at DirectAMS Radiocarbon Dating Service, USA to establish a  
210 chronology within which to place the environmental changes. The dates were calibrated using  
211 the northern hemisphere calibration of the Intcal13 curve (Reimer et al., 2013) using OxCal  
212 v4.10 (Bronk-Ramsey, 2009).

213

## 214 **3. Results**

215

### 216 **3.1. Vegetation survey and mangrove zonation in the Salak Phet area**

217 The mangrove ecosystem of Salak Phet was surveyed to show the ecological  
218 distribution and dominant mangrove species along a 400 m transect from landward to  
219 seaward (Figure 2). There were 12 mangrove species: *Acrostichum aureum*, *Avicennia*  
220 *officinalis*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Lumnitzera littorea*, *Nypa fruticans*,  
221 *Phoenix paludosa*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Sonneratia alba*, *Suaeda*  
222 *maritima* and *Xylocarpus granatum* (Figure 3). The SLP-S location was dominated by  
223 *Rhizophora mucronata* (80%) and *Bruguiera gymnorrhiza* (20%) trees. The SLP-M site was  
224 characterised by *Ceriops tagal* (70%), *Rhizophora mucronata* and *R. apiculata* (20%) and  
225 *Lumnitzera littorea* (10%) trees. The SLP-L location was dominated by *Lumnitzera littorea*  
226 (65%) and *Bruguiera gymnorrhiza* (35%) trees. At present, the SLP-L and the SLP-M  
227 locations are covered by mangroves and back mangrove taxa, while the SLP-S site is  
228 characterised mainly by seaward mangrove species. The zonation of the modern vegetation  
229 composition is related to the distance of each coring site from the sea. A zonation of the  
230 mangrove ecosystem in Salak Phet Bay has been developed based upon a combination of  
231 Watson's (1928) and Santisuk's (1983) inundation classes. There were six mangrove species  
232 and seven back mangrove species (Figure 3) in Salak Phet Bay.

233

234 (Insert Figure 2)

235

236 (Insert Figure 3)

### 237 3.2. Stratigraphy and loss on ignition

238 Each site was cored until the sediment became impenetrable when coarse sand was  
239 reached. The basal unit of the three cores consisted of dominant sub-rounded poorly sorted  
240 sand with varying concentrations of silt. Marine shells identified as *Parvicardium* sp.,  
241 *Cyclocardia* sp., *Placamen* sp., *Anomalocardia squamosal*, *Placuna* sp. (oyster) shells and  
242 shell fragments were present at the bottom layer of SLP-S and SLP-M cores (Figure 3). Peat  
243 was found at the top of the SLP-M core. Organic material, including root fragments,  
244 increased towards the upper unit of all cores with bark fragments also being present. The  
245 boundaries between stratigraphic units in all three cores are transitional. The detailed  
246 stratigraphic descriptions including grain-size, sorting, roundness, composition of the three  
247 cores are shown in Figures 3 and 4.

248 The organic and carbonate content throughout the three cores varied between 2% to  
249 40% and 0.8% to 6 %, respectively (Figures 5-7). The organic content of the three cores  
250 increased from the base to the top of the core related to the peat and root fragments in the  
251 upper units of the cores. The organic content of SLP-L ranged from 3.88% to 31.42% and  
252 sharply decreased from 10.61% to 6.53% between 80 and 70 cm related to the absence of  
253 root fragments. The SLP-M core has a very low organic content (2.28-6.06%) at the base  
254 with increased content (7.5-36.84%) in the overlying peat unit. The organic content of the  
255 SLP-S core ranged from 2.78% to 40.18 %. The organic content of SLP-S represented the  
256 highest percentages (40.18%) at 60 cm corresponding to the occurrence of bark and root  
257 fragments.

258 The carbonate content of all the cores decreased from the lower to the upper units  
259 except in the SLP-M core. The carbonate analyses recorded low percentages throughout the  
260 SLP-L core (0.88-1.91%). The carbonate content of SLP-M ranged from 1.29% to 6.57%.  
261 Samples at depths from 40 to 0 cm have the highest carbonate content (3.10-6.57%)  
262 compared to the lower sections (1.28-3.55%). The carbonate content of SLP-S ranged from  
263 0.85% to 3.91%. The percentage of carbonate content (1.35-3.61%) in the lower unit of SLP-  
264 S was higher than the other cores, corresponding to the occurrence of shells and shell  
265 fragments.

266  
267  
268  
269  
270  
271

*(Insert Figure 4)*

*(Insert Figure 5)*

*(Insert Figure 6)*

*(Insert Figure 7)*

272

### 273 **3.3. Chronological results and sedimentation rates**

274 Eight radiocarbon dates were obtained from the three cores; two from SLP-S and  
275 SLP-M and four from SLP-L (Table 1). The radiocarbon dates obtained from small bark and  
276 wood fragments indicate that the sediment deposits accumulated continuously, with a robust  
277 chronology that is in sequence although the results from the SLP-L represent a younger date  
278 at the base of sequence (118 cm) that is possibly due to sediment reworking. Although acid-  
279 based-acid pre-treatment was undertaken to prevent percolation of humic acids through  
280 leaching into the mangrove sequences (Hammond et al., 1991), the reversed date may be due  
281 to contamination through root penetration introducing younger material at lower depths. In  
282 addition, the sediment above the dates of  $864 \pm 68$  cal yr BP at 25 cm in the SLP-L show a  
283 possible hiatus, although there was no evidence of erosion identifiable from the continuous  
284 stratigraphy or the pollen assemblage. Therefore, seven radiocarbon dates (excluding the date  
285 from 118 cm of SLP-L) are used to provide a chronological framework to interpret the  
286 palaeoecological data. As no indicators of disturbance had been found in the sequence, it is  
287 assumed that a constant rate of deposition occurred in these sediment sequences. Linear  
288 regression was therefore used to construct the age-depth model (Figure 8). The overall  
289 sedimentation rates of SLP-S, SLP-M and SLP-L are  $1.4 \text{ mm a}^{-1}$ ,  $1.1 \text{ mm a}^{-1}$  and  $0.6 \text{ mm a}^{-1}$ ,  
290 respectively.

291 Organic material within mangrove sediments can be both allochthonous and  
292 autochthonous brought into the system by tides and freshwater input (Ellison and Stickland,  
293 2010). However, previous studies using wood fragments from mangrove sediment for dating  
294 (González et al., 2010; Woodroffe et al., 2015a) have proved that dating small wood  
295 fragments may yield more reliable ages compared to bulk sediments or rootlets that may be  
296 affected by younger mangrove material or old carbon reworking (Woodroffe et al., 2015a).  
297 However, other approaches such as using organic concentrates (Woodroffe et al., 2015b) or

298 pollen concentrates (Vandergoes & Prior, 2003) have been used to eliminate the  
 299 allochthonous and reversal factors.

300

301 (Insert Figure 8)

302

303 Table 1 Radiocarbon dates from Salak Phet mangrove areas including calibrated ages using  
 304 the northern hemisphere calibration of the Intcal13 curve (Reimer et al., 2013) in the  
 305 programme OxCal v4.10 (Bronk-Ramsey, 2009).

306

| Core  | Depth (cm) | Code         | Type of samples | Fraction of modern pMC | <sup>14</sup> C yr BP | cal yr BP |
|-------|------------|--------------|-----------------|------------------------|-----------------------|-----------|
| SLP-S | 95         | D-AMS 026633 | Bark            | 88.28±0.26             | 1001 ± 24             | 884 ± 81  |
| SLP-S | 163        | D-AMS 025455 | Wood fragments  | 87.50±0.26             | 1073 ± 24             | 993 ± 62  |
| SLP-M | 75         | D-AMS 026634 | Bark            | 93.83±0.27             | 512 ± 23              | 529 ± 21  |
| SLP-M | 149        | D-AMS 022267 | Wood fragments  | 83.91±0.33             | 1409 ± 32             | 1324 ± 40 |
| SLP-L | 25         | D-AMS 026635 | Bark            | 88.70±0.28             | 963 ± 25              | 864 ± 68  |
| SLP-L | 85         | D-AMS 026636 | Bark            | 83.51±0.26             | 1448 ± 25             | 1342 ± 41 |
| SLP-L | 100        | D-AMS 028366 | Bark            | 82.40±0.28             | 1555 ± 27             | 1457 ± 69 |
| SLP-L | 118        | D-AMS 025456 | Wood fragments  | 86.38±0.26             | 1176 ± 24             | 1093 ± 87 |

307

308

### 309 3.4. Pollen analysis

310 Pollen analyses on the three cores of Salak Phet Bay were undertaken and the data  
 311 classified into four groups based on the ecological categories (Table 2). Pollen diagrams were  
 312 zoned based on similar floristic composition using a stratigraphically constrained cluster  
 313 analysis.

314

315 Table 2 Mangrove pollen present in the sediment cores based on ecological categories.

| Group          | Species                          | Core  |       |       |
|----------------|----------------------------------|-------|-------|-------|
|                |                                  | SLP-L | SLP-M | SLP-S |
| Mangroves      | <i>Avicennia</i>                 | X     | X     | X     |
|                | <i>Bruguiera/Ceriops</i>         | X     | X     | X     |
|                | <i>Rhizophora</i>                | X     | X     | X     |
|                | <i>Sonneratia</i>                |       | X     | X     |
| Back mangroves | <i>Acanthus</i>                  |       |       | X     |
|                | <i>Acrostichum</i>               |       | X     | X     |
|                | Chenopodiaceae cf. <i>Suaeda</i> |       | X     | X     |
|                | <i>Lumnitzera</i>                | X     | X     | X     |
|                | <i>Oncosperma</i>                | X     |       | X     |

|                        |                    |   |   |   |
|------------------------|--------------------|---|---|---|
| Terrestrial herbaceous | Asteraceae         |   |   | X |
|                        | Cyperaceae         | X |   | X |
|                        | Poaceae            | X | X | X |
|                        | Polygalaceae       | X |   |   |
| Non-mangrove arboreal  | Arecaceae          | X | X | X |
|                        | <i>Casuarina</i>   |   | X |   |
|                        | <i>Croton</i>      |   | X |   |
|                        | Dipterocarpaceae   |   |   | X |
|                        | <i>Elaeocarpus</i> |   |   | X |
|                        | Euphorbiaceae      | X | X | X |
|                        | Fagaceae           | X | X | X |
|                        | <i>Lagerstomia</i> |   | X |   |
|                        | Myrtaceae          | X | X | X |
|                        | <i>Pinus</i>       |   | X | X |
|                        | Sapindaceae        |   |   |   |
|                        | Tiliaceae          | X |   | X |

316

317

318 *Pollen zone descriptions of SLP-S core*

319 The pollen diagram of SLP-S core was divided into two zones; SLP-S-1 (165-95 cm)  
320 and SLP-S-2 (95-0 cm) as shown in Figure 5.

321

322 SLP-S-1 (165-95 cm: ~1000-880 cal yr BP)

323 Mangrove taxa have the highest representation (74-59%) followed by back mangrove  
324 (8-27%), non-mangrove arboreal (9-23%), terrestrial herbaceous (0-3%) and unknown pollen  
325 (0-3%) respectively. Mangrove taxa are characterised by *Rhizophora* (38-58%),  
326 *Bruguiera/Ceriops* (4-16%), *Avicennia* (1-5%) and *Sonneratia* sp. (0-1%). *Oncosperma* (6-  
327 19%) has the greatest abundance among back mangrove taxa with a peak of 19% at the base  
328 of the core followed by *Lumnitzera* (1-9%), *Acrostichum* (1-5%) and *Acanthus* (0-3%). Non-  
329 mangrove arboreal taxa are present in this zone with Arecaceae, Dipterocarpaceae,  
330 *Elaeocarpus*, Euphorbiaceae, Fagaceae, Myrtaceae, *Pinus* and Tiliaceae. Terrestrial  
331 herbaceous pollen are rare with only Asteraceae, Cyperaceae and Poaceae present. Pollen  
332 concentration fluctuates from 3576 to 10,675 grains cm<sup>-3</sup>.

333

334 SLP-S-2 (95-0 cm: ~880 cal yr BP to present)

335 Mangrove taxa are the primary group (65.3-90.5%) in this zone characterised by  
336 *Rhizophora*, *Avicennia* and *Bruguiera/Ceriops*. Back mangrove is characterised by the rapid  
337 decrease of *Oncosperma* from the bottom to the top of this zone with percentages of 1-5%



338 while *Lumnitzera* (1-7%), *Acrostichum* (0-4%), and *Acanthus* (0-1%) decrease gradually.  
339 Non-mangrove arboreal taxa mainly Fagaceae (0-4%) and Myrtaceae (0-4%) also decrease to  
340 low percentages. Terrestrial herbaceous taxa show an increase of Poaceae (up to 4%) with  
341 few Asteraceae and Cyperaceae. Pollen concentrations are higher than the previous zone  
342 (3975-37,619 grains cm<sup>-3</sup>).

343

#### 344 *Pollen zone descriptions of SLP-M core*

345 The pollen diagram of SLP-M core was divided into three zones; SLP-M-1 (150-135  
346 cm), SLP-M-2 (135-15 cm) and SLP-M-3 (15-0 cm) as shown in Figure 6.

347

#### 348 *SLP-M-1 (150-135 cm: ~1300-1200 cal yr BP)*

349 There is a high representation of mangrove taxa (55-68%) especially *Rhizophora*  
350 pollen (54-50%) followed by *Bruguiera/Ceriops* pollen (3-6%) and *Avicennia* pollen (1-7%).  
351 Pollen and spores of back mangroves are present (12-17%), characterised by *Oncosperma*  
352 (16-9%), which has the greatest abundance among back mangrove taxa with a peak of 16% at  
353 the base of the core, *Lumnitzera* (1-3%) and *Acanthus* (0-1%). Non-mangrove arboreal taxa  
354 are present at the bottom of the zone (24-11%) including *Pinus* (1-3%), Fagaceae (3-8%),  
355 Arecaceae (3-5%), Myrtaceae (0-2%) and *Largerstomia* (0-2%). Pollen concentrations are  
356 low (7,527-12,142 grains cm<sup>-3</sup>).

357

#### 358 *SLP-M-2 (135-75cm: ~1200-530 cal yr BP)*

359 Mangrove taxa (79-92%) increase in this zone and are characterised by *Rhizophora*  
360 (61-70%) *Bruguiera/Ceriops* (5-22 %) followed by *Avicennia* (1-9 %) and *Sonneratia* sp. (0-  
361 1%) while pollen and spores of back mangroves decrease from the bottom of the zone (3-  
362 11%) and increase towards the top. Terrestrial herbaceous taxa increase to 0-7% with  
363 Poaceae pollen (0-6%). Pollen from non-mangrove arboreal taxa are present (1-10%)  
364 dominated by Arecaceae (0-7%). Pollen concentration fluctuates between 13,590 to 90,619  
365 grains cm<sup>-3</sup>.

366

#### 367 *SLP-M-3 (75-0 cm: ~530 cal yr BP to present)*

368 This zone contains the greatest abundance of mangrove pollen (84-97%) with  
369 *Rhizophora* (50-67%) followed by *Bruguiera/Ceriops* (10-41%) and *Avicennia* (0-5%) while  
370 back mangrove taxa (0-6%) are characterised by *Lumnitzera* (0-6%) and *Oncosperma* (0-  
371 4%). Non-mangrove arboreal taxa consist of Fagaceae pollen at 3%. Terrestrial herbaceous

372 taxa (0-7%) gradually decrease. Pollen concentration ranges from 9,601 to 90,619 grains cm<sup>-3</sup>.  
373

374

375 *Pollen zone descriptions of SLP-L core*

376 The pollen diagram of SLP-L core was divided into three zones; SLP-L-1 (120-  
377 85cm), SLP-L-2 (85-25 cm) and SLP-L-3 (25-0 cm) (Figure 7).

378

379 SLP-L-1 (120-85 cm: Prior to ~ 1460-1340 cal yr BP)

380 Mangrove taxa (68-85%) namely *Rhizophora* (54-69%), *Bruguiera/Ceriops* (36-  
381 52%), and *Avicennia* (2-11%) have the highest representation in this zone. Back mangrove  
382 taxa (5-8%) are characterised by *Lumnitzera* (1-8%) and *Oncosperma* (0-7%). Non-mangrove  
383 arboreal taxa (6-12%) mainly contain Fagaceae (4-6%) and Tiliaceae (0-3%). Terrestrial  
384 herbaceous taxa (0-9%) in particular *Polygala* (0-6%) increase towards the top of the zone  
385 and Poaceae (0-3%) is present. Pollen concentrations are relatively high (15,597-55,676  
386 grains cm<sup>-3</sup>) with peaks at 100-90 cm.

387

388 SLP-L-2 (85-25 cm: ~1340-860 cal yr BP)

389 Mangrove taxa remain dominant in this zone characterised by *Rhizophora* (63-78%),  
390 *Bruguiera/Ceriops* (7-11%), and *Avicennia* (1-4%). *Avicennia* and *Bruguiera/Ceriops* and  
391 increase towards the top of this zone. Back mangrove taxa show an increase of *Lumnitzera*  
392 (4-12%) with a marked decline of *Oncosperma* (0-4%). Non-mangrove arboreal taxa (1-6%)  
393 characterised by Fagaceae (1-4%), Myrtaceae (0-1%) and Tiliaceae (0-2%) decrease at the  
394 beginning of this zone but increase at the top. Areaceae, Euphorbiaceae are rarely found <  
395 1%. Poaceae (0-7%) is present throughout the zone and increase to the top while Cyperaceae  
396 (<1%) is present only at 30 cm. The pollen concentration values are low at 10,214-54,650  
397 grains cm<sup>-3</sup>.

398

399 SLP-L-3 (0-25 cm: ~860 cal yr BP to present)

400 Mangrove taxa (69-84%) including *Rhizophora* (53-68%), *Bruguiera/Ceriops* (14-  
401 15%) and *Avicennia* (0-1%) increase at the beginning and then decline at the top of the zone.  
402 Back mangroves taxa (13-16%) increase from the bottom to the top dominated by *Lumnitzera*  
403 (11-15%). *Oncosperma* (<0.7%) sharply decreases. Percentages of terrestrial herbaceous taxa  
404 (1-12%) dramatically increase with Poaceae at 1-12%. Non-mangrove arboreal taxa decrease  
405 to 1%. The pollen concentration is 21,328-36,433 grains cm<sup>-3</sup>.

406

407

#### 408 **4. Interpretation and Discussion**

409           The mangrove ecosystem and coastal environment in Salak Phet was reconstructed  
410 using a combination of palaeoecological indicators consisting of stratigraphical analysis,  
411 pollen analysis, loss on ignition and radiocarbon dating. In addition, the data from the  
412 contemporary mangrove zonation of six mangrove species and seven back mangrove species  
413 in Salak Phet Bay was used to aid the interpretation of ecosystem and environmental change  
414 through the fossil record as follows. *Rhizophora mucronata* and *Sonneratia alba* are pioneer  
415 species found at the seaward edges where *S. alba* is inundated by medium to all high tides  
416 and *R. mucronata* is inundated by normal to all high tides (Santisuk, 1983; Tomlinson, 1986).  
417 *S. alba* is mostly found in soft mud and sand in seafront locations and is intolerant of long  
418 periods of exposure to freshwater (Taylor et al., 2003; Giesen et al., 2007). *Rhizophora*  
419 species are seaward inhabiting species with *R. mucronata* dominating in wet, muddy soils  
420 and form large homogeneous stands on upper river banks and creeks (Chapman, 1976; Taylor  
421 et al., 2003). In addition to these two species, *Rhizophora apiculata* inhabits soft and muddy  
422 soils (Giesen et al., 2007) that are inundated by spring to medium high tides. *Bruguiera*  
423 *gymnorhiza* and *Ceriops tagal* are upper intertidal species; *B. gymnorhiza* being found  
424 between *R. mucronata* and *C. tagal* (Taylor et al., 2003) in areas inundated by abnormal to  
425 normal high tides (Santisuk, 1983). *C. tagal* appears in the upper intertidal and dry areas  
426 inundated by spring to normal high tides; it prefers clay substrates (Giesen et al., 2007) and  
427 has a weaker root system that is unable to withstand strong waves (Taylor et al., 2003).  
428 *Avicennia officinalis* is also inundated by abnormal tides to normal high tides, it grows on the  
429 landward margins of true mangrove or along tidal river banks characterised by sandy clay  
430 sediments (Pumijumnong, 2014; Giesen et al., 2007). The back mangroves are characterised  
431 by *Nypa fruticans* and *Xylocarpus granatum* in an area inundated by abnormal tides to  
432 normal high tides. *Nypa fruticans* usually forms pure stands but sometimes grows with other  
433 species such as *Lumnitzera racemosa* (Kusmana, 2014). *Xylocarpus granatum* occurs along  
434 landward fringes of mangrove and brackish water environments where freshwater has more  
435 influence, and the environment is less saline (Taylor et al., 2003; Giesen et al., 2007).  
436 *Acrostichum aureum* is also inundated by abnormal tides to spring high tides. It occurs in  
437 brackish creeks and rivers and prefers soils with a wide range of salinity (Medina et al., 1990;  
438 Giesen et al., 2007). *L. racemosa* is characteristic of the landward fringe of many mangrove  
439 communities with high salinity, sandy substrate and also inundated by abnormal tides to

440 spring high tides (Gallin et al., 1989; Giesen et al., 2007). There are two back mangrove  
441 species that are found in this area that are inundated by only abnormal tides; *Phoenix*  
442 *paludosa* and *Suaeda maritima*. *P. paludosa* is usually found in the landward margin of  
443 mangroves and also in the area bordering the estuarine water and land (Rao, 1972). This  
444 species is associated with dry areas and grows on dry, clay and brackish to saline soils  
445 (Giesen et al., 2007).

446 The three cores (SLP-S, SLP-M and SLP-L) record a cross-core similarity in  
447 stratigraphy containing a lower unit of increased sorted sand that becomes increasingly  
448 organic with root and bark fragments up-core. The dominance of sub-rounded poorly sorted  
449 sand in all cores (Figure 4) possibly indicated that the sediments were deposited fairly close  
450 to the source area of igneous mountains that cover most of Koh Chang (Pumijumnong &  
451 Payomrat, 2013). It is also possible that storm events may have deposited the poorly sorted  
452 sand. However, there was no evidence of erosion or the presence of a sharp stratigraphical  
453 boundary that would support this hypothesis. In addition, a study on storm deposits along the  
454 coastal area of the Gulf of Thailand revealed that washover deposits from storm are well-  
455 sorted medium to very fine-grained sand with heavy minerals (Phantuwoongraj & Choowong,  
456 2012) none of which were identified at Salek Phet Bay.

457 The mangrove pollen through the sediment sequence was used to reconstruct coastal  
458 ecosystem dynamics, sea-level changes and recent human impacts by examining the  
459 dominant mangrove pollen in each core as a proxy. *Rhizophora* was found to be dominant in  
460 all of the cores extracted and was used to indicate a lower intertidal area inundated by all high  
461 to spring tides. *Rhizophora* pollen are recognised as being dispersed from local sources,  
462 therefore representing their source plants very well but being over-represented as they are a  
463 wind-pollinated species (Muller, 1959; Somboon, 1990; Van Campo & Bengo, 2004;  
464 Punwong et al., 2013a; 2013b). Studies on mangrove pollen representation (Behling et al.,  
465 2001; Ellison, 2005; Ellison & Strickland, 2013) showed that proportions of more than 50%  
466 of modern surface mangrove pollen including *Rhizophora* and other mangrove species such  
467 as *Bruguiera* and *Avicennia* indicate a mangrove environment. The vegetation survey  
468 undertaken at each of the coring sites corresponded to the pollen found in the uppermost  
469 levels of 10 cm of the cores.

470

#### 471 ***Circa 1500-500 cal yr BP***

472 Following a mid-Holocene highstand, a marine regression occurred in the Gulf of  
473 Thailand and other Southeast Asia regions commencing at around 6000 cal yr BP (Tjia, 1996;

474 Sinsakul, 2000; Tanabe et al., 2003; Horton et al., 2005; Mallinson et al., 2014). The Salak  
475 Phet Bay record presented here started around 1500 cal yr BP with a high representation of  
476 *Rhizophora*, accompanied by other mangrove species; *Avicennia*, *Bruguiera/Ceriops* and  
477 *Sonneratia* sp. at the beginning of SLP-L-1 zone indicating that Salak Phet Bay had been  
478 covered by mangrove forest by around 1500 cal yr BP. The sub-rounded poorly sorted sand  
479 layer at the bottom of all cores, combined with the pollen evidence suggests that Salak Phet  
480 Bay was a shallow marine environment during a regressive phase in the late Holocene. Salak  
481 Phet Bay then developed into an intertidal environment as the area became suitable for  
482 mangrove to establish by 1500 cal yr BP when the coastline was located farther seaward  
483 compared to the present-day. The decrease in *Rhizophora* from the bottom to the top of SLP-  
484 L-1 and the increase in non-mangrove arboreal in the zones SLP-M-1 and SLP-L-1 indicated  
485 mangrove started to migrate seaward. This ecosystem shift was possibly due to on-going sea-  
486 level fall in response to less tidal inundation allowing terrestrial conditions to exist until  
487 around 1300 cal yr BP. The sand content increases upwards in the SLP-M-1 and SLP-L-1  
488 cores coincident with decreased *Rhizophora* pollen, supporting the interpretation that at  
489 around 1500 BP sea level was falling. There is also a high representation (up to 20%) of  
490 *Oncosperma* in the SLP-L-1 and SLP-M-1 zones indicating freshwater input in Salak Phet  
491 Bay: the contemporary distribution of *Oncosperma* is in the landward fringes of brackish  
492 water swamps (Giesen et al., 2007). The predominance of *Oncosperma* in SLP-M-1 and SLP-  
493 L-1 corresponds with an appearance of Myrtaceae taxa which grows in moist habitats  
494 (Schmidt, 1902). Therefore, during the period 1500-1300 cal yr BP, it is likely that Salak  
495 Phet Bay supported a higher intertidal environment with more freshwater input than the  
496 present day.

497 Mangroves characterised by *Rhizophora* started increasing through SLP-L-2 and SLP-  
498 M-2 from around 1300 cal yr BP. SLP-L-2 contains a similar age determination (1300-900  
499 cal yr BP) to zone SLP-M-2 (slightly after 1340-500 cal yr BP) and SLP-S-1 (1000-900 cal  
500 yr BP). The increasing presence of *Rhizophora*, with an occurrence of *Oncosperma* and more  
501 silt content in SLP-M-2 and SLP-L-2 zones suggests that the Salak Phet Bay probably  
502 experienced a greater inundation frequency due to a sea-level rise occurring from around  
503 1300-900 cal yr BP resulting in mangroves migrating landward. The appearance of marine  
504 shells as *Parvicardium* spp., *Cyclocardia* spp., *Placamen* spp., *Anomalocardia squamosal*,  
505 *Placuna* spp. and shell fragments in SLP-S-1 and SLP-M-2 also suggest a sea-level rise. In  
506 addition, the present-day ecological habitat of *A. squamosa* (Roopnarine et al., 2008) found in  
507 the SLP-S core suggests that the seaward area of Salak Phet Bay was an intertidal to shallow

508 subtidal environment during this period. No shell residues were found in SLP-L possibly due  
509 to its location at a greater distance from the sea compared to the other two sites. The increase  
510 of *Rhizophora* with a decrease in upper intertidal species, *Bruguiera/Ceriops* (Santisuk,  
511 1983) at the top of zone SLP-M-2, and between the depths of 100 to 50 cm in SLP-S-2,  
512 represents a cross-core similarity dated to around 500 cal yr BP and further suggests that sea  
513 level continued rise until around 500 years ago. This interpretation is supported by the  
514 dominance of silty sand particles in the zones; SLP-M-2 and SLP-S-2. Evidence from the  
515 three cores suggests that after 1300 years, mangroves extended in Salak Phet Bay as sea level  
516 rose in this region, consistent with the Holocene sea-level curve of the east of Malay-Thai  
517 Peninsula that shows a trend of sea-level rise after 1300 cal yr BP (Tjia, 1996). Rising sea  
518 level is also recorded in the south of the Gulf of Thailand until around 500 cal yr BP before  
519 falling to the present level (Horton et al., 2005). However, these results contradict the studies  
520 undertaken on the Setiu coast, northeast of Malaysia, Malay–Thai Peninsula that indicate an  
521 episode of sea-level fall around 1400 to 300 cal yr BP (Mallinson et al., 2014) and on the  
522 western coast of the Gulf of Thailand where beach ridges recorded a sea-level fall to the  
523 present level after 1600 cal yr BP (Nimnate et al., 2015).

524         It should also be noted that from around 1500-500 cal yr BP, Salak Phet Bay was  
525 influenced by freshwater as evidenced by the presence of *Oncosperma*, together with  
526 Myrtaceae, in all three cores. The occurrence of these two taxa together with fern spores is  
527 indicative of wet conditions that appears to correlate with a similar period recorded in the  
528 northeast of Thailand; combined these studies indicate an increased summer monsoon  
529 between 1150 and 980 cal yr BP (Chawchai et al., 2015). More widely, several tree ring  
530 studies have also indicated greater magnitude monsoons in the Southeast Asia region around  
531 900-850 cal yr BP (Buckley et al., 2010; 2014). Other studies in the western upper Gulf of  
532 Thailand suggest wet conditions associated with stronger monsoon over Southeast Asia a  
533 little later between 800-700 cal yr BP (Punwong et al., 2018b) and between 700-650 cal yr  
534 BP (Buckley et al., 2010; 2014; Lieberman & Buckley, 2012). After around 700 cal yr BP,  
535 *Oncosperma* sharply decreased at Salak Phet Bay concomitant with an increase in Poaceae  
536 pollen together with a decrease in Myrtaceae, that may suggest less freshwater input in the  
537 bay from around 700 cal yr BP. This coincides with drier conditions recorded in northeastern  
538 Thailand between 650-500 cal yr BP (Chawchai et al., 2015).

539

540 ***Circa 500 cal yr BP to present***

541 After 500 cal yr BP *Rhizophora* gradually decreased from the bottom to the top of  
542 SLP-M-3 zone. This corresponds to the decrease in *Rhizophora* in the uppermost part of SLP-  
543 S-2 zone (50-0 cm) at around 500 cal yr BP to present. SLP-L-3 zone (dated from 900 cal yr  
544 BP to present) probably represents a recent sediment accumulation with increasing amounts  
545 of *Bruguiera/Ceriops*. The decrease in *Rhizophora*, and the increase in *Bruguiera/Ceriops*,  
546 are related to increased terrestrial herbaceous taxa, mainly Poaceae in all the cores suggesting  
547 that the frequency of marine inundation was further reduced as sea level fell after 500 cal yr  
548 BP allowing terrestrial vegetation to develop in Salak Phet Bay. This sea-level fall is also  
549 indicated by a higher pollen percentage of Poaceae and *Lumnitzera* and back mangrove taxa,  
550 in SLP-L-3. This interpretation is regionally supported by studies from the upper Gulf of  
551 Thailand that indicate an ongoing marine regression during the last 1000 years (Somboon &  
552 Thiramongkol, 1992; Tanabe et al., 2003), particularly after 700 cal yr BP (Punwong et al.,  
553 2018b). A study from the south of the Gulf of Thailand also suggests a lower sea level after  
554 around 500 cal yr BP (Horton et al., 2005). However, mangrove pollen in particular  
555 *Rhizophora*, show a slightly increased presence at the top of the SLP-S and SLP-M possibly  
556 reflecting recent sea-level rise. These tentative signals of mangrove response to historical sea-  
557 level rises correlate with a mangrove study from the upper Gulf of Thailand indicating sea-  
558 level rise in the last century (Punwong et al., 2018b) and a relative sea-level rise of ~ 0.7-1.2  
559 mm a<sup>-1</sup> recorded in the eastern Gulf of Thailand during the last 60 years (Trisirisatayawong  
560 et al., 2011). Koh Chang was recorded as a temporary shelter for ships from China trading  
561 with the Ayutthaya Kingdom at ~650-250 cal yr BP (AD 1300s to 1700s) during the  
562 monsoon seasons. Although there was an established fishing village in Salak Phet in the  
563 1920s (Rochanarat, 2007), anthropogenic activity is commonly recorded during the last 50  
564 years from mangrove locations in Thailand (Pumijumnong, 2014) and tourism development  
565 in Koh Chang started in the early 2000s (UNEP, 2008). Although Koh Chang was designated  
566 as National Park in 1982, the old coastal communities were not included in the preserved  
567 areas (Pumijumnong & Payomrat, 2013). Associated with this settlement and tourism  
568 development is the increased use of mangroves providing materials for building (Taylor,  
569 1982) and this could account for the recent changes in some of those taxa in Salak Phet Bay.

570 An increase in terrestrial grasses and a decrease in *Oncosperma* after 500 cal yr BP  
571 may relate to a reduction in precipitation over Southeast Asia including Vietnam and  
572 Thailand during 500-130 cal yr BP (Lieberman & Buckley, 2012) before an increase in  
573 rainfall was documented in the northwest of Thailand and Southeast Asia after around 100  
574 cal yr BP (Cook et al., 2010; Lieberman & Buckley, 2012). In addition, *Oncosperma* spp. is

575 commonly used as a resource for house construction (Dransfield et al., 2004) and jetties  
576 (Bandaranayake, 1998) and this may have been another contributory factor responsible for  
577 the recent disappearance of this taxon.

578 The pollen records from Salak Phet Bay record the responses of mangrove to sea-  
579 level change, suggesting that mangroves in the eastern Gulf of Thailand adapted to changes  
580 in sea-level that occurred in the last 1500 years. As future sea-level rise may be the one of the  
581 most important factors threatening the changing distribution of mangroves, insights into past  
582 mangrove dynamics should be used more systematically to evaluate the ability of mangrove  
583 to cope with climate change particularly sea-level rise. Given the current maximum rate of  
584 sea-level rise in the eastern Gulf of Thailand of 1.2 mm a<sup>-1</sup>, mangroves in Salak Phet Bay  
585 with average sedimentation rates of 0.6-1.4 mm a<sup>-1</sup> (Figure 8) could persist under the current  
586 scenario of sea-level rise. However, the estimated overall sedimentation rates for the past  
587 1500 years are not sufficient to keep pace with the future projections of sea level rise in the  
588 Gulf of Thailand of 0.28-0.65 m by 2100 (~3-7 mm a<sup>-1</sup>) (Sojisuporn et al., 2013). It is  
589 predicted that the coastal zone of the Gulf of Thailand will be under by seawater by 2070  
590 (Lovelock et al., 2015). The results of this study therefore suggest that the capacity to  
591 accumulate sediments in Salak Phet Bay will not be enough to maintain future mangrove  
592 ecosystems. Moreover, mangroves on small islands like Salak Phet Bay, where freshwater  
593 discharge is low, are more vulnerable to collapse under the projected sea-level rise as the  
594 sediment accumulation depends solely on tides and accommodation space for mangrove  
595 migration (Ellison, 2000). It is recommended therefore that management plans consider these  
596 factors in planning for the future, otherwise mangrove communities will disappear due to a  
597 combination of enhances sea-level rise and coastal erosion.

598

## 599 **5. Conclusions**

600 The palaeoecological records from Salak Phet Bay, Koh Chang are the first  
601 reconstruction of mangrove ecosystem dynamics from the eastern coast of Thailand for the  
602 last 1500 years. Mangrove ecosystems have been established in Salak Phet Bay from at least  
603 1500 cal yr BP suggesting this bay was located in a low intertidal environment. Mangroves  
604 subsequently decreased in extent indicating less frequent marine inundations, possibly due to  
605 a lower sea level until 1300 cal yr BP. Sea-level rise was recorded from 1300-500 cal yr BP  
606 indicated by increasing mangrove taxa, particularly *Rhizophora* and the appearance of marine  
607 shells as Salak Phet Bay experienced greater inundation frequency from 1300-500 cal yr BP.



608 Salak Phet Bay was also influenced by freshwater input as evidenced by the presence of  
609 *Oncosperma* that is coeval with an increased summer monsoon in the Southeast Asia region.

610 After 500 cal yr BP mangroves gradually decreased and terrestrial herbaceous taxa  
611 increased, suggesting that the frequency of marine inundation was further reduced as sea  
612 level fell. Drier conditions were also recorded indicated by an increase in terrestrial grasses  
613 and a decrease in *Oncosperma* after 500 cal yr BP. A subsequent increase in *Rhizophora*  
614 pollen may reflect a recent sea-level rise, although changes in plant composition may relate to  
615 recent human activities within Koh Chang. The average rate of sedimentation in Salak Phet  
616 Bay suggested that although mangroves of Koh Chang kept pace with the past 1500 years and  
617 current rates of sea-level change, they may not be capable of surviving under future predicted  
618 sea-level rise scenarios.

619

620

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## 959 **Figure captions**

960 Figure 1 Location map of Koh Chang (A) Koh Chang with mangrove areas boxed (B) Map of  
961 mangrove areas and coring sites in Salak Phet Bay.

962

963 Figure 2 Study site and mangrove area of Salak Phet Bay from seaward (A) to landward (F).

964 Figure 3 A cross section showing the ecological distribution and dominant mangrove species  
965 from landward to seaward in the Salak Phet mangrove area and coring sites including the  
966 stratigraphic details of SLP-S, SLP-M and SLP-L cores.

967

968 Figure 4 Images of sediment composition in SLP-S, SLP-M and SLP-L cores

969

970 Figure 5 Pollen diagram of SLP-S core showing percentage pollen frequency and loss on  
971 ignition analyses.

972

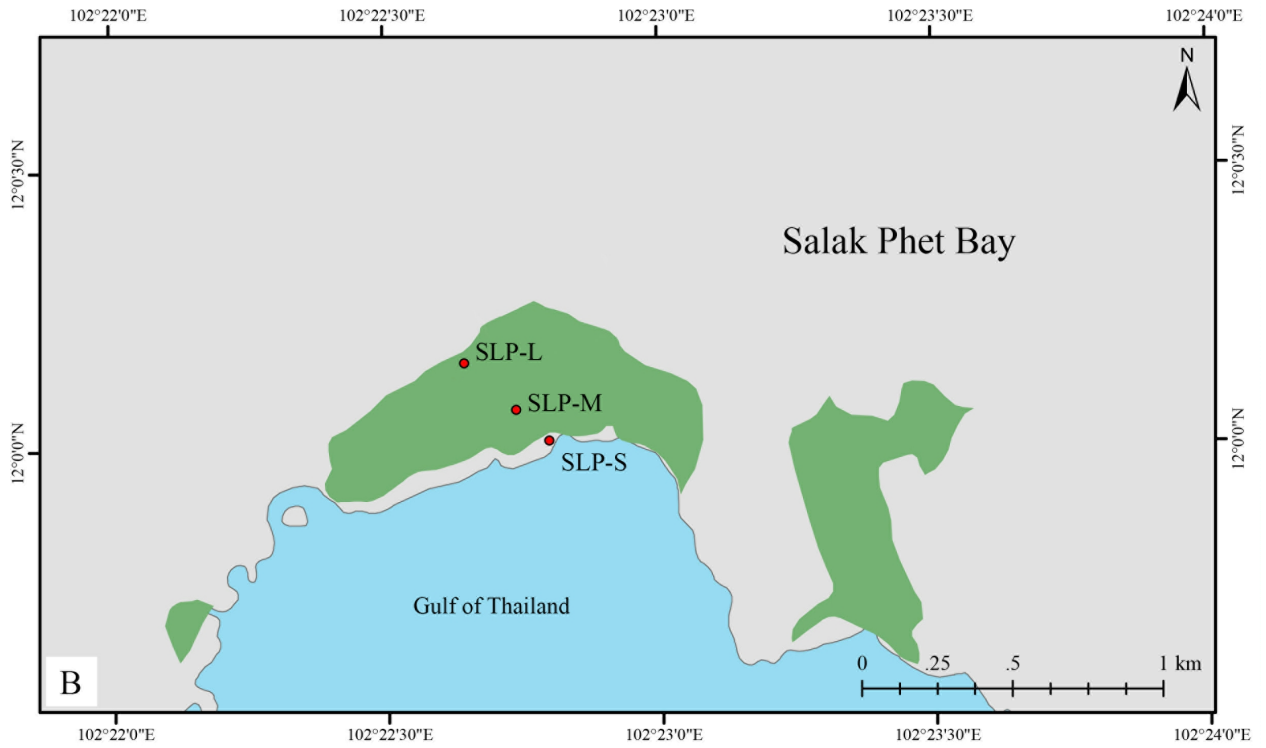
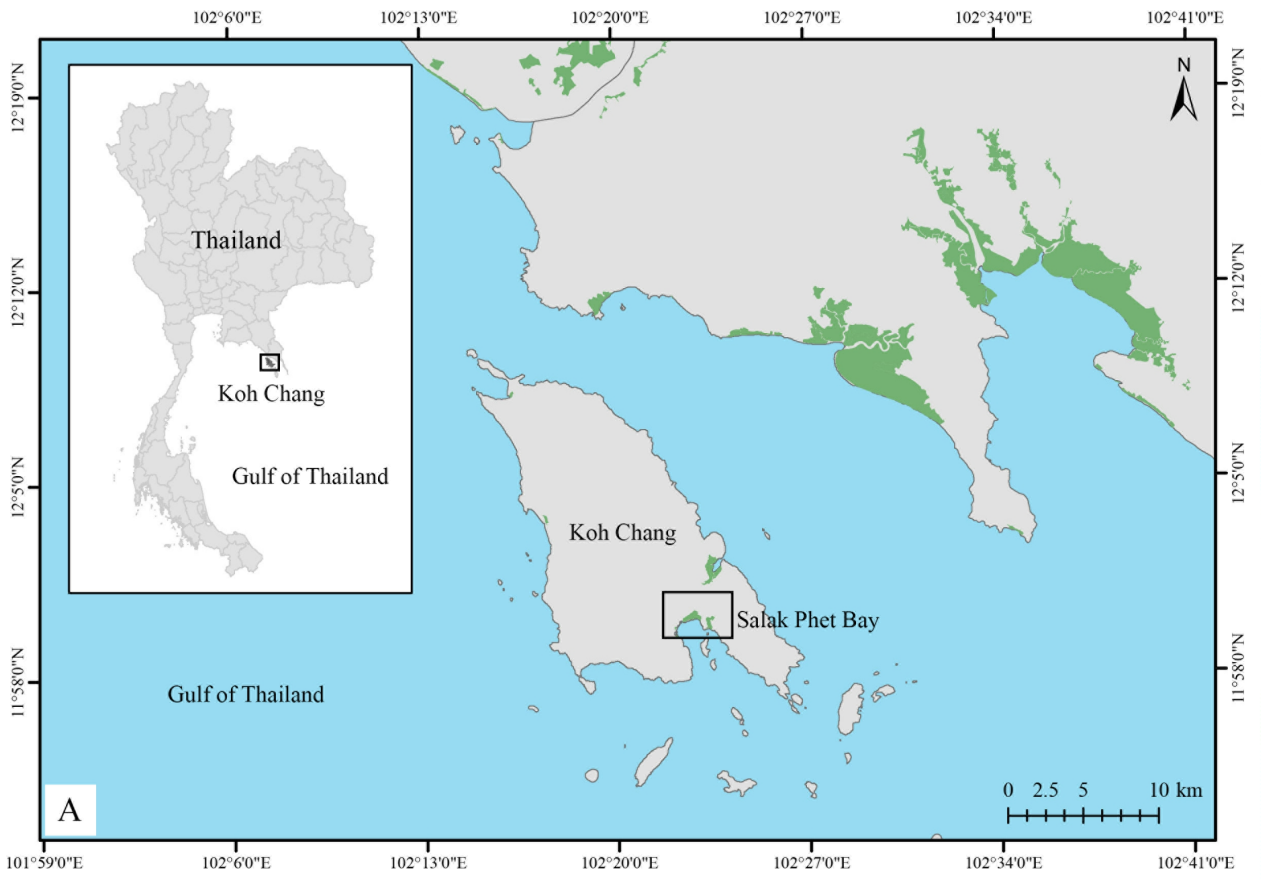
973 Figure 6 Pollen diagram of SLP-M core showing percentage pollen frequency and loss on  
974 ignition analyses.



975

976 Figure 7 Pollen diagram of SLP-L core showing percentage pollen frequency and loss on  
977 ignition analyses.

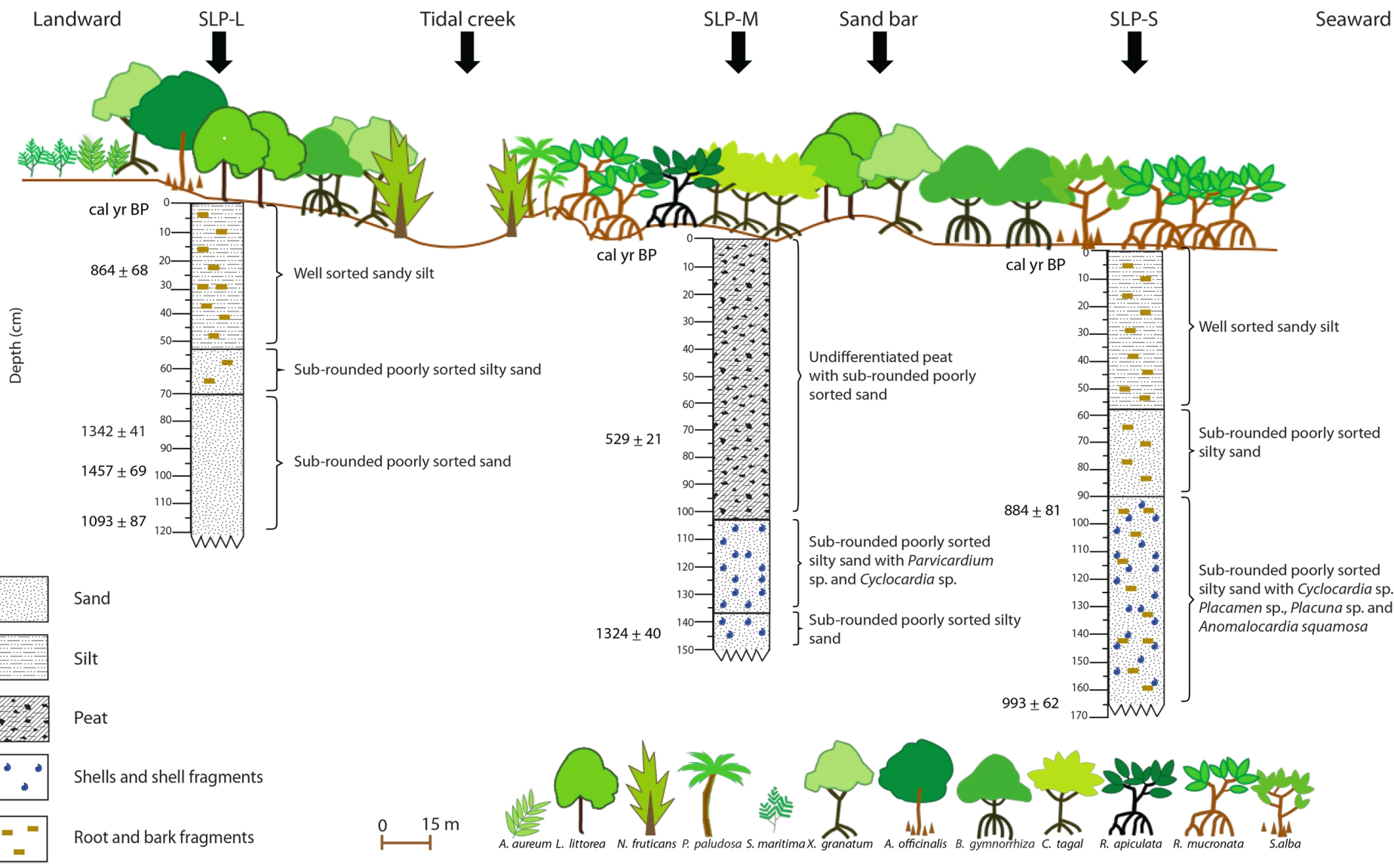
978 Figure 8 Age-depth relationship plots for SLP-S, SLP-M and SLP-L cores.

979



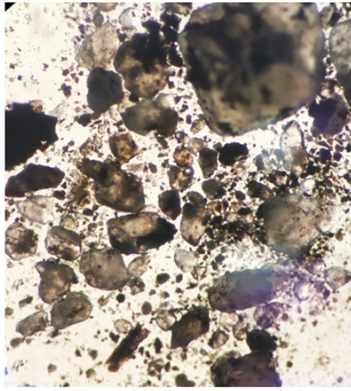
 Mangroves      Coring sites





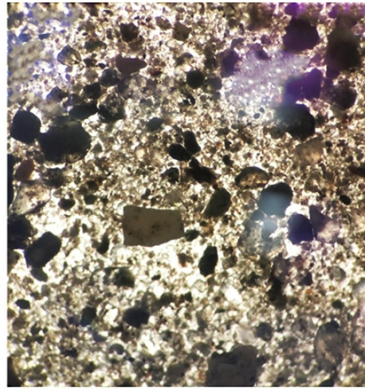
**SLP-L**

120-90 cm



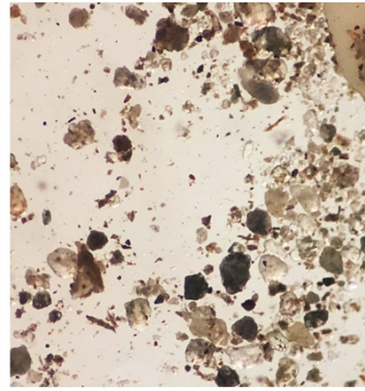
**SLP-M**

150-137 cm

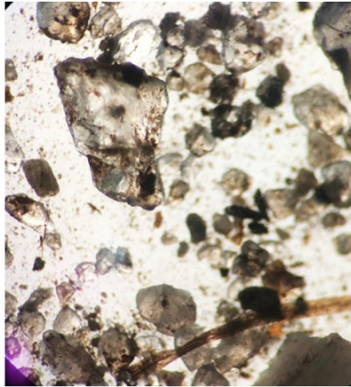


**SLP-S**

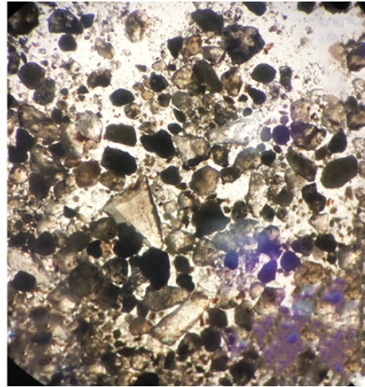
165-100 cm



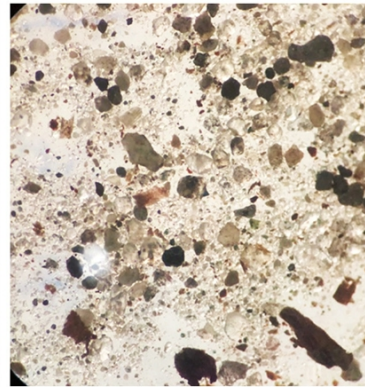
90-70 cm



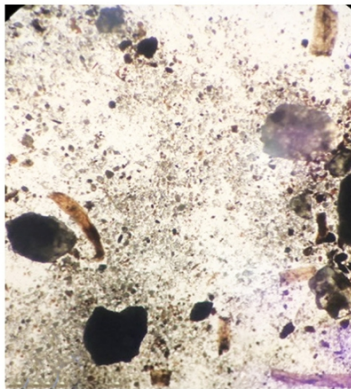
137-103 cm



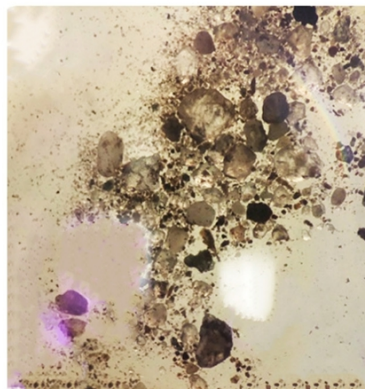
100-90 cm



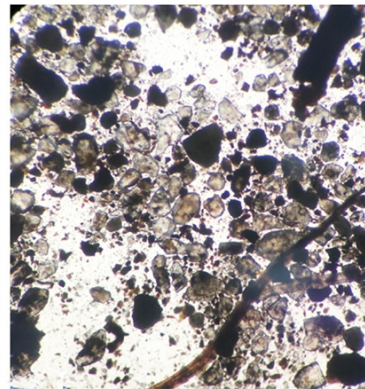
53-70 cm



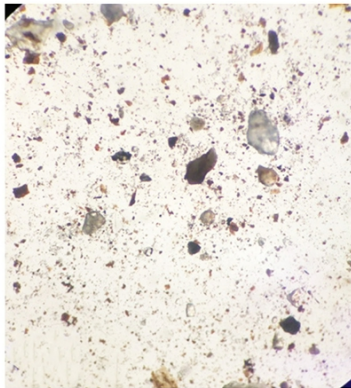
103-80 cm



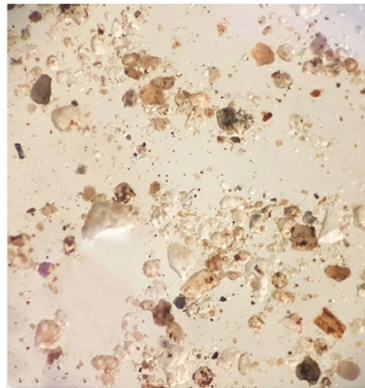
90-57 cm



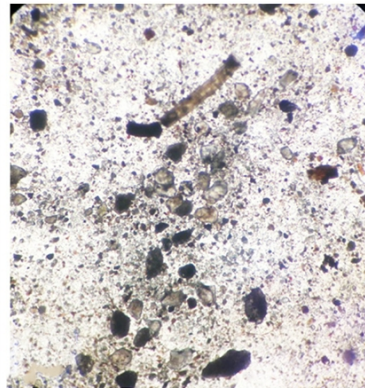
53-0 cm



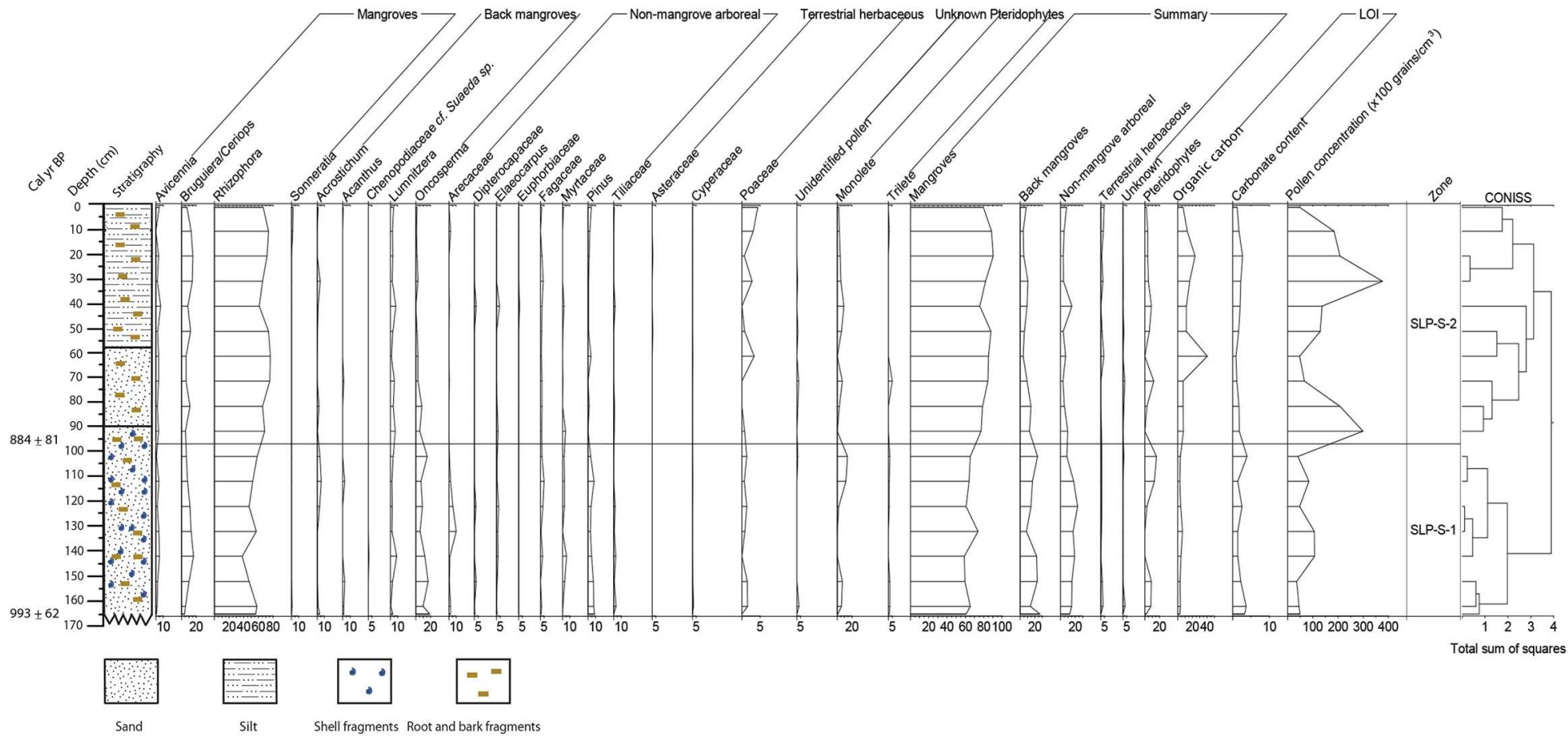
80-0 cm

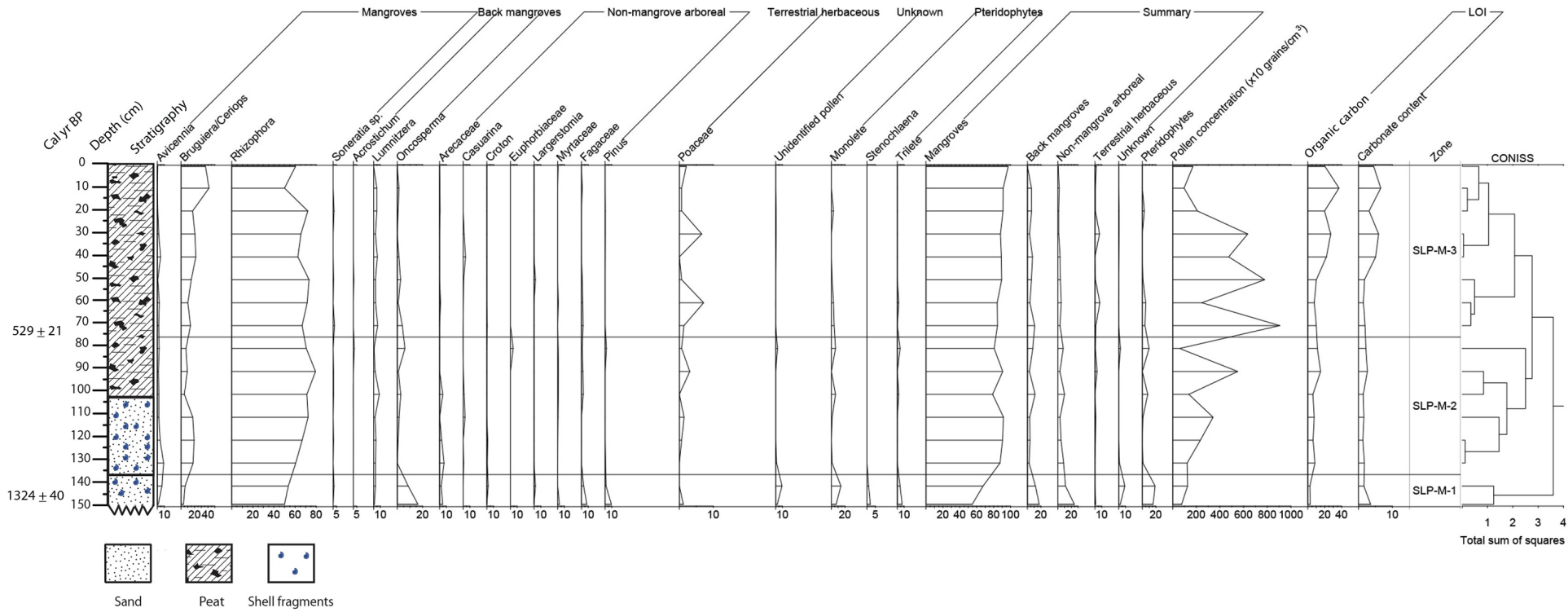


57-0 cm

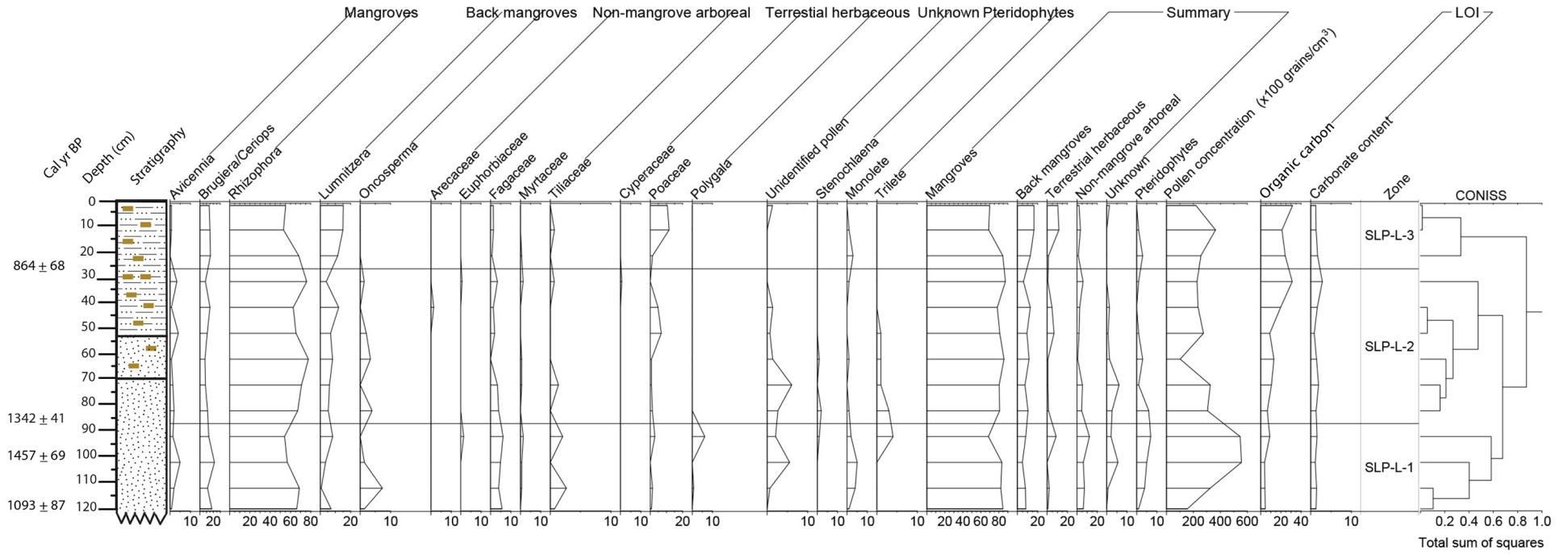








Total sum of squares



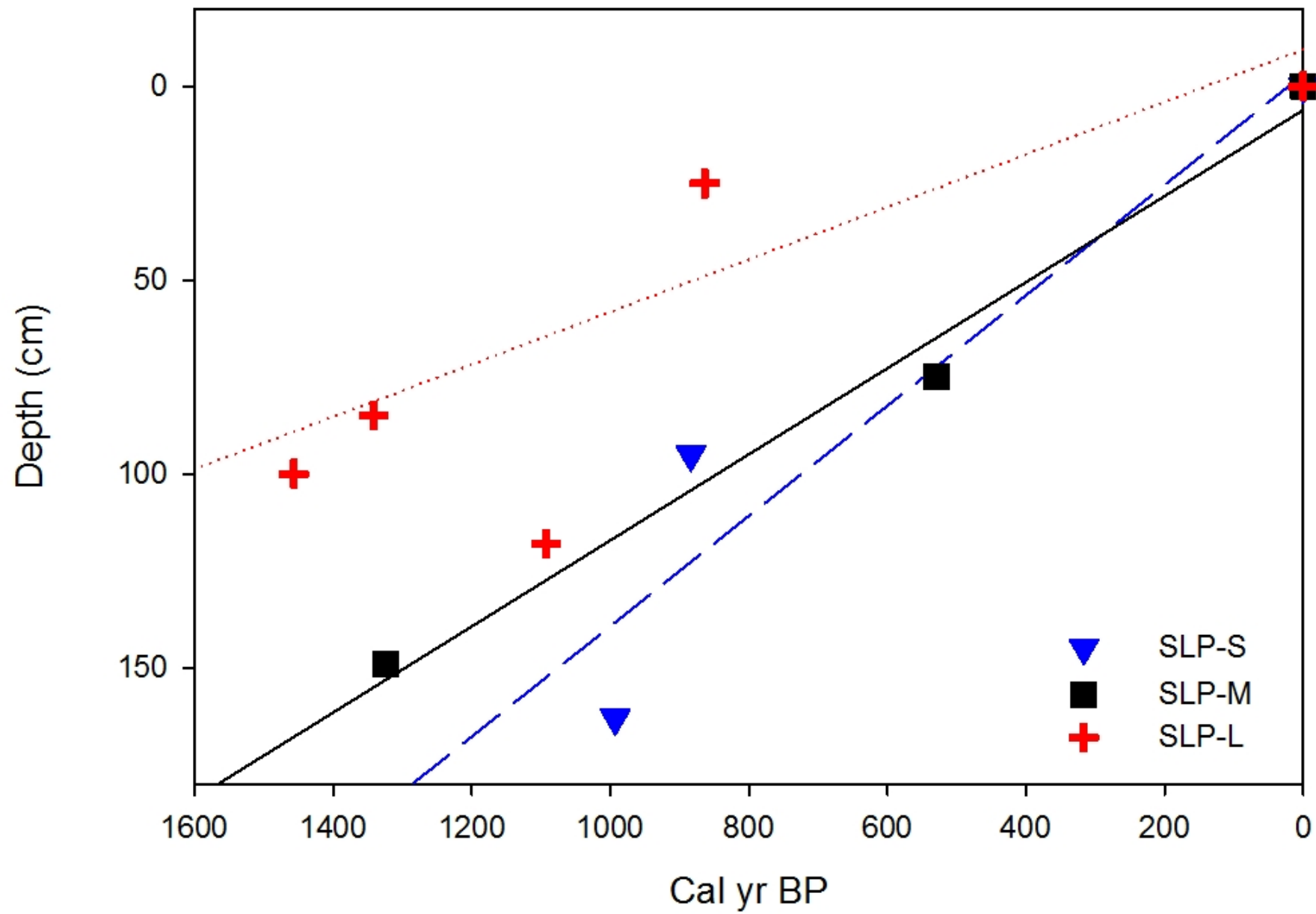
Sand



Silt



Root and bark fragments



## Quaternary International

We the authors declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We understand that the Corresponding Author is the sole contact for the Editorial process. He/She is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

Sincerely,

On behalf of all authors



Miss Apichaya Englong 17/09/2018



Dr. Rob Marchant 17/09/2018



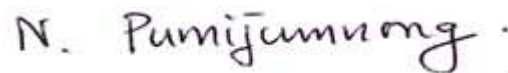
Dr. Paramita Punwong 17/09/2018



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