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► **To cite this version:**

Li Zhang, Jianping Liu, Zezhong Gao, Lei Zhang, Dongmei Wan, et al.. Comparative analysis of hissing calls in five tit species. Behavioural Processes, 2019. hal-03024842v1

**HAL Id: hal-03024842**

**<https://cnrs.hal.science/hal-03024842v1>**

Submitted on 25 Nov 2020 (v1), last revised 26 Nov 2020 (v2)

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1 **Comparative analysis of hissing calls in five tit species**

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18 **Word count:** 4571

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21 **Running headline:** Hissing calls in tit species

22

23 **Abstract**

24 Nest predation often leads to breeding failure, and is an important selective  
25 pressure of natural selection that affects nest defense behavior in birds. Many tit  
26 species give a hissing call for nest defense, but there are few studies on  
27 interspecific variation in hissing calls and whether these are related to nest  
28 predation and nesting success. In this study, we compared the hissing calls of  
29 five tit species including cinereous tit (*Parus cinereus*), marsh tit (*Poecile*  
30 *palustris*), varied tit (*Sittiparus varius*), willow tit (*Poecile montanus*), and coal  
31 tit (*Periparus ater*) in Saihanba National Forest Park in Hebei and Xianrendong  
32 National Nature Reserve in Liaoning. In Saihanba of Hebei, the proportion of  
33 individuals giving a hissing call and nest predation were similar among three tit  
34 species (cinereous, varied, and marsh tits). In Xianrendong of Liaoning, the  
35 proportion of cinereous, varied, and marsh tit individuals giving a hissing call  
36 differed significantly but nest predation did not. Cinereous and varied tits  
37 showed no differences in clutch size, date of the first egg, nest predation and  
38 nesting success between individuals that gave and those that did not give a  
39 hissing call. These results indicated that for tit species that breed in nest boxes  
40 distributed within the same area, there is interspecific variation in hissing calls,  
41 but these are not significantly correlated with nest predation risk.

42

43 **Keywords:** hissing call, nest defense, nest predation, repeatability, Paridae.

44

45 **Introduction**

46 Nest predation often leads to failed reproduction and is a major selective  
47 pressure that affects nest defense behavior in birds (Ricklefs 1969; Martin 1995;  
48 Forstmeier and Weiss 2004; Fontaine and Martin 2006; Lima 2009; Tilgar and  
49 Moks 2015; Fu et al. 2016; Guppy et al. 2017). Birds have evolved complex  
50 anti-predation strategies to protect their nests and demonstrate specific  
51 behaviors when facing predators of different types and risk levels (Lima et al.  
52 2005; Yorzinski and Vehrencamp 2009; Krams et al. 2010; Yorzinski and Platt  
53 2012; Suzuki 2011, 2015; Daniela et al. 2018; Maziarz et al. 2018). For  
54 example, when blue peacock (*Pavo cristatus*) encounters a raccoon during the  
55 day, it calls loudly, stretches its neck, opens its wings, and strikes a flying pose  
56 as it approaches the predator. However, at night it will instead remain silent and  
57 give a soft hissing call (Yorzinski and Platt 2012).

58 In animals sound is often used to transmit predator information  
59 (Zuberbühler 2009; Fasanella and Fernández 2009; Suzuki 2011, 2014, 2015;  
60 Fuong et al. 2014; Townsend et al. 2014). Individuals of the same or different  
61 species use this acoustic information to evade predation (Sherman 1977; Pipia  
62 et al. 2009; Kitchen et al. 2010; Suzuki 2011, 2015; Gill and Bierema 2013;  
63 Townsend and Manser 2013). For example, Japanese tits (*Parus minor*) give  
64 different warning sounds to indicate the predator type: the “jar” sound is used to  
65 indicate a Japanese rat snake (*Elaphe climacophora*) whereas the “chicka”  
66 sound indicates a jungle crow (*Corvus macrorhynchos*) (Suzuki 2014). When

67 chicks hear the “jar” sound coming from the female they jump out of the nest to  
68 evade predation by the snake, but upon hearing the “chicka” sound they instead  
69 huddle in the nest to avoid being preyed upon (Suzuki 2011).

70       Some birds have also developed acoustic Bayesian mimicry that simulates  
71 the sound of a toxic, inedible, or more dangerous species so as to gain security  
72 benefits (Gaul 1952; Sibley 1955; Klump and Shalter 1984; Apel and Weise  
73 1986; Rowe et al. 1986; Owings et al. 2002; Kelly et al. 2008; Zub et al 2017).  
74 When it senses invasion by a predator, the bird stretches its wings forward and  
75 down rapidly in a curve, raises and extends its tail, and gives a spontaneous  
76 hissing call (Perrins 1979; Cramp and Perrins 1994) that leads to its  
77 misidentification as a snake by the predator, which is then discouraged from  
78 approaching (Cox 1930; Sibley 1955; Rowe et al. 1986; Perrins 1979; Krams et  
79 al. 2014). For example, the hissing call of burrowing owl (*Athene cunicularia*)  
80 simulates the crackling sound of alerted Prairie rattlesnakes (*Crotalus viridis*)  
81 and is used to scare off its predator, the California ground squirrel  
82 (*Spermophilus beecheyi*) (Rowe et al. 1986).

83       Hissing calls are common in cavity breeding birds including tits (Odum  
84 1942; Hinde 1952; Sibley 1955; Apel and Weise 1986; Broughton 2005, 2012).  
85 In many tit species, females incubate the eggs while males scarcely engage in  
86 alerting behavior or assist with nest defense (Perrins 1979). A recent study  
87 showed that hissing females of great tits (*Parus major*) survive better than silent  
88 females (Krams et al. 2014). Playing recordings of the hissing calls of the great

89 tit, Eurasian blue tit (*Cyanistes caeruleus*), and marsh tit (*Poecile palustris*)  
90 affected nest exploration by their predators, the yellow-necked mouse  
91 (*Apodemus flavicollis*) (Zub et al. 2017). Among different tit species breeding in  
92 the same area, rates of nest predation are lower for those that exhibit hissing  
93 behavior than for those that do not (Walankiewicz 2002; Wesołowski 2002;  
94 Czeszczewik 2004; Wesołowski and Rowiński 2012; Maziarz et al. 2016).  
95 However, hissing calls of many tit species have not yet been investigated.  
96 Moreover, there is little information on whether there are interspecific variation  
97 in hissing calls of tit species located in the same area, and whether the hissing  
98 call of a species is related to its life history traits.

99 To address these questions, in this study we compared the hissing calls of  
100 five tit species located in the same area. For sympatric breeding cinereous and  
101 varied tits, we also investigated whether there are differences in the breeding  
102 parameters of individuals with or without a hissing call, such as date of the first  
103 egg, clutch size, nest predation rate and nesting success in order to determine  
104 the relationship between hissing call and breeding performance.

105

## 106 **Materials and methods**

### 107 **Study area and study species**

108 The Saihanba National Forest Park (SHB) is located in Weichang, 240 km from  
109 Chengde City, Hebei Province (42°02'–42°36' N, 116°51'–117°39' E) at an  
110 altitude of 1,350–1,650 m. The park has a semi-arid/semi-humid cold-

111 temperature continental monsoon climate and is the main natural secondary  
112 forest and plantation forest area in Hebei. Within the park there are plateaus,  
113 mountains, forests, and grasslands (Fig. 1; Liu et al. 2017).

114 The Xianrendong National Nature Reserve (XRD) is located in Zhuanghe,  
115 Liaoning Province (39°54'–40°03' N, 122°53'–123°03' E) at an altitude of 200–  
116 600 m. It is adjacent to the Yellow Sea and is located in a warm, temperate,  
117 humid monsoon climate zone (Fig. 1; Du et al. 2010).

118 Tits belong to the Paridae family, which comprises small passerine birds  
119 that are mainly distributed in the Northern hemisphere and Africa. These small,  
120 stocky, woodland species have short bills and a length of 10–22 cm (Gosler and  
121 Peter, 2007). The great tit, which were originally distributed in Eurasia, are now  
122 classified as three separate species: great tits from Europe to Northwestern Asia,  
123 the cinereous tit (*Parus cinereus*) of South Asia, and the Japanese tit of East  
124 Asia (Päckert et al. 2005).

125 In 2018, the birds attracted to artificial nest boxes hung in SHB were  
126 mainly cinereous tits, willow tits (*Poecile montanus*), and coal tits (*Periparus*  
127 *ater*) (Fig. 1, A-C). Between 2016 and 2018, the birds that were attracted to nest  
128 boxes hung in XRD were mainly cinereous, marsh, and varied tits (*Sittiparus*  
129 *varius*) (Fig. 1, D-F).

130

### 131 **Field data collection**

132 The nest boxes, particularly those used by tits, were routinely examined during  
133 the breeding season. Hatching status was determined according to clutch size  
134 and date of the first egg. The date on which the female laid the last egg was  
135 defined as day 0 of the incubation period. In this study, the incubation period of  
136 each of the five tit species was approximately 12 days. We divided the  
137 incubation period into three stages: early, mid and late incubation. The nest box  
138 was inspected once during each stage. When we opened the lid of the nest box  
139 during the inspection, some of the tits gave a hissing call instead of escaping  
140 from the nest. Depending on the response of the female upon opening the nest  
141 box, we divided the birds into those with or without hissing calls. During the  
142 field work, we found that the hissing call behavior of the five tit species was  
143 highly repeatable—i.e., individuals that did not give a hissing call at the start of  
144 the study did not give any hissing calls during the whole breeding period.

145 Nest predation rate was defined as the proportion of predated nests to the  
146 total nests monitored (Krams et al. 2014). Nesting success was defined as the  
147 proportion of successful nests (success to fledge at least one young), and it was  
148 a dichotomous variable for measuring predation intensity (Pribil 1998).

149

## 150 **Statistical analysis**

151 Statistical analysis was performed using SPSS v.16.0 for Windows (IBM,  
152 Armonk, NY, USA). The one-sample Kolmogorov-Smirnov test was used to  
153 analyze the normality of the data. When the data normality condition was met,



154 the t-test or one-way analysis of variance was used to compare mean values.  
155 Otherwise, non-parametric tests—i.e., the Mann-Whitney U test and Kruskal-  
156 Wallis test—were used. All tests were two-tailed, with a significance level of  $P$   
157  $< 0.05$ . Data are expressed as mean  $\pm$  standard deviation (mean  $\pm$  SD).

158 The number of tits with hissing calls in the two study areas were as follows:  
159 in SHB, 32 nests of cinereous tits, 17 nests of coal tits, and eight nests of willow  
160 tits were found to give hissing calls in 2018. In XRD, 48 nests of varied tits and  
161 45 nests of cinereous tits in 2016; and 39 nests of varied tits, 40 nests cinereous  
162 tits, and 17 nests of marsh tits in 2018 were found to give hissing calls. Since no  
163 breeding of marsh tits was recorded in XRD in 2016, and the proportion of  
164 varied tits giving hissing calls differed significantly between the 2 years, only  
165 the 2018 data were included when analyzing interspecies differences of hissing  
166 calls of tits located in the same area of Liaoning. However, both the 2016 and  
167 the 2018 data were used when analyzing differences in the reproductive  
168 parameters of birds with and without hissing calls.

169

## 170 **Results**

171 During 2018 in SHB, 19 out of 32 (59.4%) cinereous tits, 14 out of 17 (82.3%)  
172 coal tits, and 3 out of 8 (37.5%) willow tits gave hissing calls. There were no  
173 significant differences among hissing calls of the three tit species located in the  
174 same area (Fig. 2;  $P = 0.076$ , Fisher's exact test).

175 During 2018 in XRD, 16 out of 39 (41.0%) varied tits, 24 out of 40 (60.0%)  
176 cinereous tits, and 3 out of 17 (17.6%) marsh tits gave hissing calls. Significant  
177 differences were observed among hissing calls of the three tit species located in  
178 the same area (Fig. 2;  $P = 0.011$ , Fisher's exact test).

179 In SHB, none of the 66 cinereous tits and 45 coal tits and only one of the  
180 31 willow tit nests were depredated. There were no significant differences in  
181 predation rates among the three tit species ( $P > 0.05$ , Fisher's exact test).

182 In XRD, 18 out of 39 (46.2%) varied tits, 14 out of 40 (35.0%) cinereous  
183 tits, and 8 out of 19 (42.1%) marsh tits were targeted by predators. There were  
184 no significant differences in predation rates among the three tit species ( $P = 0.$   
185  $597$ , Fisher's exact test). For a total of 51 depredated nests, 30 nests were  
186 confirmed to be depredated by mice (10%; 3 out of 30 nests) or snakes (90%;  
187 including Korean rat-snakes *Elaphe anomala* and steppe rat-snakes *E. dione*).

188 For cinereous tits, 62 tits gave hissing calls whereas 23 tits did not. The  
189 date of the first egg and clutch size did not differ significantly between the two  
190 groups of tits [ $9.75 \pm 1.31$  ( $n = 60$ ) vs.  $9.77 \pm 1.23$  ( $n = 22$ )] ( $P = 0.880$ , Mann-  
191 Whitney U test). Similar rates of nest predation (19.4% vs. 30.4%) and nesting  
192 success (64.5% vs. 52.2%) were also observed between the two groups (Fig. 3;  
193  $P > 0.05$ , Fisher's exact test).

194 For varied tits, 52 tits gave hissing calls whereas 37 tits did not. The two  
195 groups were similar in terms of date of the first egg and clutch size ( $7.31 \pm 1.08$   
196 vs.  $7.10 \pm 1.12$ ) ( $P = 0.264$ , Mann-Whitney U test) as well as nest predation

197 (21.6% vs. 30.8%) and nesting success (56.8% vs. 44.2%) (Fig. 3;  $P > 0.05$ ,  
198 Fisher's exact test).

199

## 200 **Discussion**

201 Nest predation is one of the major causes of death in birds, and it has led to the  
202 evolution of morphological, physiological, and behavioral strategies to avoid  
203 predation (Lima 2009; Parejo et al. 2013; Fu et al. 2016). Previous work showed  
204 that cavity breeding tits give hissing calls to frighten approaching predators  
205 (Rowe et al. 1986; Zub et al. 2017) and thereby increase the survival rate of  
206 female birds and fledglings (Krams et al. 2014). Our study indicated that in  
207 SHB, there were no significant differences in the proportion of cinereous,  
208 willow, or marsh tit giving hissing calls. In contrast, in XRD, differences were  
209 observed in the proportions of cinereous, varied, and marsh tits. However, in  
210 both SHB of Hebei and XRD of Liaoning, nest predation rates of tits breeding  
211 in nest boxes located in the same area were similar. Cinereous and varied tits  
212 showed no differences in clutch size, date of the first egg, nest predation rate  
213 and nesting success between birds with and those without hissing calls.

214 Tit species in the wild are known to give hissing calls (Pickens 1928;  
215 Sibley 1995). However, there has been few studies investigating interspecific  
216 variation in hissing calls of tit species (Sibley 1995; Krams et al. 2014; Koosa  
217 and Tilgar 2016; Zub et al. 2017). An early report suggested that the hissing  
218 calls of tits was an acoustic form of Bayesian mimicry and provided a brief

219 description of the hissing calls of different species (Sibley 1995). In this study,  
220 we recorded in detail the hissing calls of five tit species located in the same area  
221 and investigated interspecific differences. In SHB of Hebei, we found that  
222 between cinereous and willow tits, there was no difference in the proportion of  
223 individuals giving a hissing call. However, in XRD of Liaoning, the proportions  
224 differed among cinereous, varied, and marsh tits. We found that 60% of  
225 individual cinereous tits gave a hissing call; this is comparable to the 70%  
226 reported in a previous study in which hissing calls of great tits were found to  
227 substantially reduce the predation rate of breeding females (Krams et al. 2014).  
228 The hissing call of tits was also shown to discourage nest exploration behavior  
229 of yellow-necked mouse (*Apodemus flavicollis*) (Zub et al. 2017). However, tit  
230 species differing in the proportion of individuals giving a hissing call did not  
231 have lower nest predation rate. In SHB, artificial nest boxes were mainly  
232 distributed in plantations located in areas where there were few snakes and  
233 Swinhoe's striped squirrels (*Tamiops swinhoei*)—two of the natural predators of  
234 tits—due to the high altitude and low temperature. In contrast, in XRD, nest  
235 predation rates of cinereous, varied, and marsh tits did not differ despite  
236 variation in the proportion of individuals with hissing calls. This is because the  
237 main nest predators in this area were Korean and steppe rat-snakes, which are  
238 not affected by the hissing calls of tits. The nest predation rate is markedly  
239 lower for great tits when compared to those without hissing calls (Krams et al.  
240 2014). However, comparison of nest predation rates in cinereous and varied tits

241 was similar for individuals with and without hissing calls. A possible reason for  
242 this discrepancy is our small sample size (85 cinereous and 89 varied tits vs.  
243 477 samples in the study by Krams et al. 2014). Additionally, predators in their  
244 study were mainly European pine marten (*Martes martes*), least weasel  
245 (*Mustela nivalis*), and great spotted woodpecker (*Dendrocopos major*), which  
246 are more likely scared off by the snake-like hissing calls of great tits than the  
247 predators in our study area (mainly snakes).

248 Hissing calls are unrelated to the breeding performance of female birds  
249 (Koosa and Tilgar 2016). For example, females with and without hissing calls  
250 were found to lay a similar clutch size. Our results support this observation.  
251 Furthermore, we also determined that the hissing calls of all five tit species are  
252 unrelated to nest predation risk.

253 In conclusion, our results showed that hissing calls are common among  
254 sympatrically breeding tit species such as cinereous, willow, coal, marsh, and  
255 varied tits. In SHB of Hebei, the hissing calls of cinereous, willow, and coal tits  
256 showed no interspecific variation. In XRD of Liaoning, although the proportion  
257 of individuals giving hissing calls was higher in cinereous as compared to marsh  
258 tits, the two species had similar predation risk. In addition, the hissing calls of  
259 cinereous and varied tits were unrelated to nest predation risk or life history  
260 traits such as date of the first egg, clutch size and nesting success. The present  
261 study demonstrated the behavioral adaptations of different tit species to nest

262 predation, which can in turn provide insight into the life history traits of  
263 members of the Paridae family.

264

265 **Ethics.** The experiments reported here comply with the current laws of China.  
266 Fieldwork was carried out under the permission from Saihanba National Forest  
267 Park and Xianrendong National Nature Reserve, China. Experimental  
268 procedures were in agreement with the Animal Research Ethics Committee of  
269 Hainan Provincial Education Centre for Ecology and Environment, Hainan  
270 Normal University (permit no. HNECEE-2011-001).

271

272 **Data accessibility.** Data used in this study are available in Electronic  
273 Supplementary Materials.

274

275 **Authors' contributions.** The research idea was developed from discussion with  
276 APM. DW and WL designed the study; LZ, JL, ZG and LZ performed field  
277 experiments; LZ and JL carried out laboratory and statistical analyses. JL wrote  
278 the draft manuscript, and WL and APM revised and improved the manuscript.  
279 All authors approved the final submission.

280

281 **Competing interests.** The authors declare that they have no competing interests.

282

283 **Funding.** This work was funded by the National Natural Science Foundation of  
284 China (no. 31772453 to WL and no. 31872231 to DW).

285

286 **Acknowledgments.** We are grateful to the anonymous referees for their  
287 constructive comments that significantly improved this manuscript. We thank  
288 Saihanba National Forest Park and Xianrendong National Nature Reserve for  
289 their help and cooperation, Chunlei Jing and Congying Zhang for their  
290 assistance with field work.

291



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- 428

429 **Legends to figures**

430

431 **Figure 1.** Study areas and study species in this study. Capital letters (A-F) refer  
432 to bird species and lower case letters (a-f) refer to nest and eggs. A and D refer  
433 to cinereous tit; B refers to coal tit; C refers to willow tit; E refers to varied tit;  
434 and F refers to marsh tit.

435

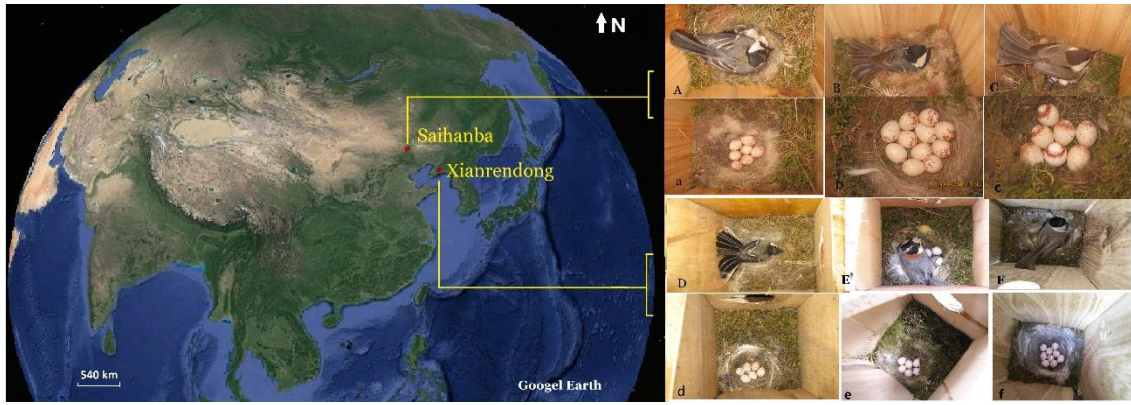
436 **Figure 2.** Proportion of hissing individuals in five tit species at two study sites.

437

438 **Figure 3.** Comparison of nesting success between individuals with hissing call  
439 and individuals without hissing call in cinereous and varied tits.

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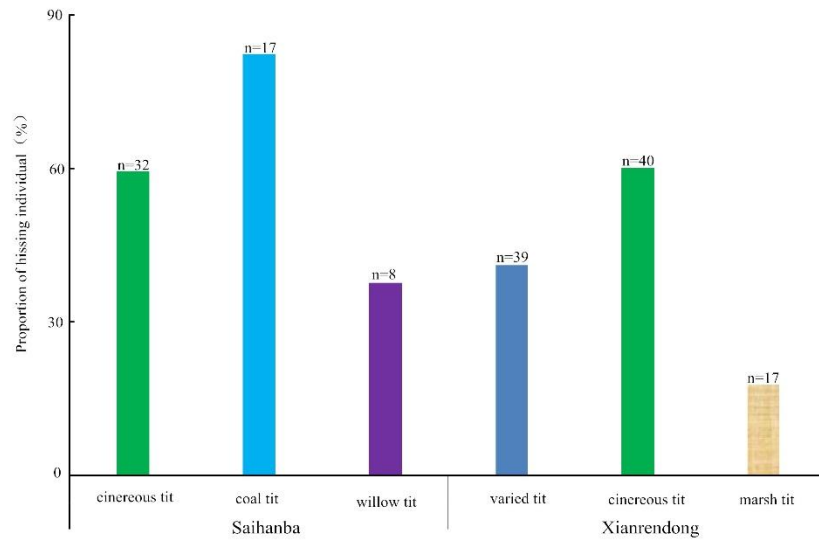




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442 **Fig. 1**

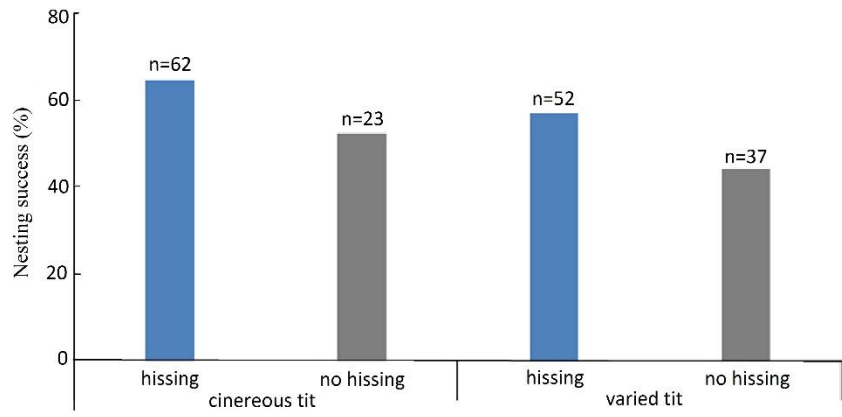
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444

445 **Fig. 2**

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448 **Fig. 3**