Cryptogamie, Mycologie, 2004, 25 (1): 57-81

Correlation between the *in vitro* growth response to temperature and the habitat of some lignicolous fungi from papua new guinea coastal forests

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Abstract – In the framework of a study of the ecology of wood-inhabiting fungi from a tropical forest on the north coast of Papua New Guinea, the effect of temperature on the *in vitro* growth of 66 lignicolous fungi (41 Polyporaceae, 9 Hymenochaetaceae, 4 Pleurotaceae, 4 Xylariaceae, 2 Ganodermataceae, 2 Corticiaceae, 1 Stereaceae, 2 Auriculariaceae, 1 Schizophyllaceae) was studied. The results showed a good correlation between the behaviour in culture and the characteristics of the habitat, especially the density of the vegetation cover. This is specially striking if one considers the species respectively with the narrowest and the broadest ecological amplitude. A first group showed in culture a narrow spectrum with a well marked growth optimum at around 30°C which is the average local temperature. This group of species (*Auricularia* cf. *mesenterica, Coriolopsis caperata, Daedalea sprucei, Hexagonia tenuis, Hypoxylon haematostroma, Microporus affinis, Microporus xanthopus, Phellinus adamantinus, Phellinus cesatii, Phellinus glaucescens, Phellinus melanodermus, Polyporus squamosus, Rigidoporus lineatus, Stereum lobatum, Trametes demoulinii, Xylaria papyrifera* and *Xylocoremium hoffmannii*) is restricted to dense vegetation cover and thus grows in an environment buffered against temperature variations. The second group showed in culture a growth optimum over a wide range of temperatures. This group of species (*Coriolopsis floccosa, Coriolopsis polyzona, Flavodon flavus, Gloeophyllum striatum, Lentinus concinnus*, *Lentinus squarrosulus, Lentinus strigosus, Pycnoporus sanguineus, Schizophyllum commune, Trametes menziezii, Trametes pavonia, Trametes scabrosa* and *Trametes villosa*) showed a very large ecological amplitude. These species are encountered under dense vegetation as well as in open habitats, and are thus exposed to large temperature variations. An interesting feature from the standpoint of biodiversity distribution is that core area of forests with more buffered temperature contain a high diversity of species, which would not be able to grow outside those forests. Some subcosmopolitan species (*Schizophyllum commune, Gloeoporus dichrous*) show a spectrum in agreement with their wide latitudinal distribution, while *Polyporus squamosus* seems at the limits of it possible growth in an equatorial environment.

Basidiomycetes / Fungi / Lignicolous / Tropical forest / Temperature

INTRODUCTION

The biological decay of wood is a very significant ecological and economic phenomenon. Without the activity of lignicolous fungi the forest floor would be covered by a thick carpet of dead wood.Although the fungi are not the only organisms able to degrade the main wood constituents (lignin and cellulose), they certainly, work primarily performed by Basidiomycetes which thus play a fundamental role in the carbon cycle of forest ecosystems. (Cooke & Rayner, 1984; Rayner & Boddy, 1988; Boddy, 1991; Durrieu 1993; Boddy & Watkinson, 1995). They are also promising organisms for industrial applications especially in paper manufacturing and in the field of bioremediation given their ability to catalyse the degradation of stable pollutants such as DDT, PCB and PCP in soil and ground water (Leatham, 1992; Kirk, 1993; Reid, 1995; Pointing, 2001).

In moist tropical areas, where the climate is specially favourable for lignicolous fungi, knowledges about these organism are still limited. This is particularly the case for South-East Asia, where even the taxonomic inventory is still incomplete.

The aim of this study was to contribute to the study of the ecology of wood-decaying fungi by the investigation of the *in vitro* growth response to temperature of tropical species.

Temperature directly affects the metabolic activities of the fungi (e.g. assimilation, translocation, respiration and synthesis). It is thus of importance for the control of biodegradation as well as the industrial use of fungal strains. Further, information on temperatures lethal to fungi in wood during processing is important to the wood processor, since survival of these fungi in products can lead to subsequent decay problems (Zabel & Morrell, 1992).

While temperature's effect on growth of fungi has been widely studied (Cartwright & Findlay, 1934; Deverall, 1965; Zabel & Morrell, 1992; Cooke & Whipps, 1993; Griffin, 1994), this has mostly been done for temperate species and it is interesting to study it for species which have been recorded in an area where the substrate has a temperature which can reach at least 35°C (Castillo & Demoulin, 1994).

MATERIAL AND METHODS

Area studied

The strains used in this study were isolated from coastal forests in Madang Province, especially from Laing Island and closed areas on the northern coast of Papua New Guinea. Laing Island is a small coral island (850 m long and 150 m wide) in the Hansa Bay (UTM BR 6338, 4°10'S/144°52'E.). It was the seat of the King Leopold III Biological Station and as such has been studied by several biologists making it a model ecosystem for the tropical coastal biota of the indo-pacific. The climate (Bouillon *et al.*, 1986; Claereboudt *et al.*, 1990) comprises a rainy season, typically from November to April with a mean monthly rainfall from 156 to 216 mm and a dry season from May to October with a mean monthly rainfall from 49 to 109 mm. The average monthly rainfall was 129.6 mm during the period 1978 to 1985. The temperature fluctuates little during the year and is 28.7 °C on average, reaching 32.5°C during the day and 29.5°C during the night (extremes 34°C and 22°C).

Terrestrial vegetation has been mapped by De Sloover (1992) and consists of three main types: beach vegetation, coastal forest and mangrove type swampy forest.

The phenology of 96 lignicolous Basidiomycetes from Laing Island has been studied by Castillo & Demoulin (1998) and among those showing a large phenological amplitude, two groups were distinguished: on the one hand a group of species (*Hexagonia tenuis*, *Polyporus philippinensis* and *Microporus xanthopus*) with a narrow ecological amplitude, restricted to dense vegetation cover, and thus growing in an environment buffered against desiccation. On the other hand, there is a group of species (*Pycnoporus sanguineus*, *Schizophyllum commune* and *Trametes scabrosa*) with a very large ecological amplitude, which grow in both dense and open vegetation and have a better resistance to desiccation.

Distribution of several wood rotting fungi on Laing Island and data on temperature and moisture of their substrate have been reported by Castillo & Demoulin (1994). The studies showed a clear link between the distribution of some fungi and the degree of vegetation cover which controls temperature and dessiccation of substrates. Variations of 27 to 35°C have been observed in a stump in open habitat while variations were limited to 28 to 30°C in a similar stump under dense forest cover. Particular attention was also given to the combined effects of salt and temperature, salt spray being an important ecological parameter for species growing close to the sea (Castillo & Demoulin, 1997).

Strains used

All strains were isolated by explants of basidiocarpe (vouchers deposited in LG) on malt agar, either by A. Nihoul (AN), V. Demoulin (VD), P. Georis (PDG) or G. Castillo (GC).

Growth experiments

A 2.5×2.5 mm piece was cut from the edge of a growing culture on malt-agar medium (Merck, pH 5.6). The cultures were then incubated in the dark at temperatures of 15, 20, 25, 30, 35, 40, 45 and 50°C. Each experiment was undertaken in triplicate.

The diameter of the culture was measured every day for 7 days. The value accepted was the mean of three measurements by Petri dish. Growth was expressed as surface growth which gives good graphic expression and the maximum daily surface growth considered the maximal growth speed. When no growth was observed at a given temperature after 7 days, the culture was transferred for 1 month to room temperature. If no growth was observed after 1 month the initial temperature was considered lethal and in the case of resumption of growth, this temperature was considered as growth inhibiting temperature. When reporting optimum, growth inhibiting or lethal temperature it should be kept in mind to use the best estimate with a 5°C interval. For example if we cite "lethal temperature 50°C" this means between 45 and 50°C.

It should be noted that optimum growth temperature on wood is often lower by 2 to 3°C to that on malt-agar (Rayner & Boddy, 1988).

RESULTS AND DISCUSSION

The species are presented in alphabetical order and their behaviour in culture correlated with the ecological observations made *in situ*.

1. *Abundisporus roseoalbus* (Jungh.) Ryvarden. (GC 122): see fig. 13.

With an optimum at 35°C or slightly lower, this spectrum resembles that of *Lenzites elegans* which however does not grow at 40°C. Moreover this species has a growth rate which is generally lower than *Lenzites elegans*. This species was found only under dense vegetation cover; considering the high temperature of inhibition, it can probably tolerate a large variation in insolation conditions.

Growth inhibiting temperature: 50°C Lethal temperature: 50°C

2. *Auricularia* cf. *mesenterica* (Dicks: Fr.) Pers. (GC 39, GC 129 & GC 273): see fig. 3.

Optimum very marked at 30°C with a high growth rate at 25°C. These temperatures agree well with the fact that this species was mainly encountered under dense vegetation cover.

Growth inhibiting temperature: 40°C Lethal temperature: 50°C

3. *Auricularia polytricha* (Mont.) Sacc. (GC 281): see fig. 3.

This species with a broad ecological amplitude, collected in all seasons, on deadwood on the ground, under dense vegetation cover or at the edge of the forest near the coast, shows an atypical spectrum for its habitat. The optimum is at 25°C with still a high growth rate at 20°C and 30°C. Its spectrum corresponds more to a fungus confined to under vegetation cover, on very wet substrate cooled by evaporation, just like *Protomerulius africanus*. Its broad growth range from 15°C to 40°C can explain its presence from densely covered to sun exposed areas and its pantropical distribution.

Growth inhibiting temperature: > 40°C Lethal temperature: 45°C

4. *Coriolopsis asper* (Jungh.) Teng. (GC 440 & GC 1337): see fig 4.

Broad spectrum with an optimum between 30°C and 35°C. This behaviour in culture agrees well with its ecology. This species has been collected in dry seasons as well as in wet seasons (Castillo & Demoulin, 1998) and generally at the edge of a path with a semi-open recovery vegetation.

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

5. *Coriolopsis* aff. *byrsina* (Mont.) Ryvarden. (GC 31): see fig. 5.

This strain was collected under dense vegetation cover. The reduction of growth rate for temperatures higher than 35°C agrees well with its ecology. The optimum is between 30°C and 35°C, the real optimal value probably being located close to 35°C. These data indicate that this species could probably grow under vegetation cover as well as in open habitats.

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

6. *Coriolopsis caperata* (Berk.) Murr. (GC 91): see fig. 5.

Coriolopsis caperata was collected in semi-open vegetation. This agrees well with its spectrum which shows a very marked optimum at 35°C and a still high growth rate at 40°C.

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

7. *Coriolopsis floccosa* (Jungh.) Ryvarden (AN 30, GC 324 & GC 394): see fig. 5.

This species was collected during the dry season on dead and even burned substrates, sometime with direct insolation, which suggests a certain thermophilous character. The optimum of growth in culture extending between 35°C and 40°C (the real optimal value being probably located between these two temperatures) agrees well with this type of habitat.

Growth inhibiting temperature: 35°C Lethal temperature: 50°C

8. *Coriolopsis polyzona* (Pers.) Ryvarden (AN 21, AN 23, AN 65 & AN 102): see fig. 4.

The 4 strains have similar growth spectra with an optimum between 30°C and 40°C, closer to 35°C for AN 23 and AN 102 and to 40°C for AN 21 and AN 65. This behaviour in culture reflects the wide ecological spectrum of this species collected on dead trunks on the ground, under dense vegetation cover as well as in zones exposed to direct insolation.

Growth inhibiting temperature: 50°C Lethal temperature: > 50°C

9. *Daedalea sprucei* Berk. (GC 415): see fig 6.

Our observation is based on a single collection made under dense vegetation cover. The *in situ* observation agrees well with the spectrum obtained. It presents a very marked optimum at 30°C. This spectrum indicates that this species is confined to dense vegetation cover in thermically buffered zones.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

10. *Daldinia eschscholzii* (Ehrenb.) Rehm (GC 24, GC 59 & AN 60): see fig. 7.

The three strains show very similar spectra with a marked optimum between 30°C and 35°C, whereas the growth rate is almost nill at 40°C. This spectrum does not agree very well with the ecology since this species is very often collected at the edge of the sea, where the temperature can reach values up to 50°C under the effect of direct insolation. It should be mentioned that strains AN 60 and GC 59 show a lethal temperature of 50°C, but for strain GC 24 this temperature is not lethal. The mycelium of this species can probably tolerate temperatures higher than 50°C in nature, but for durations shorter than those to which we exposed our cultures.

Growth inhibiting temperature: 50°C Lethal temperature: ≥ 50°C

11. *Epithele laingiana* G. Castillo, A. Nihoul & V. Demoulin*. (GC 280): see fig. 8.
* to be published

This species, collected only under dense vegetation cover on small dead branches on the ground or still suspended, presents a very low marked optimum at 25°C, a growth rate close to the optimum at 30°C and a growth rate decreased only by 50 % at 20°C. This type of spectrum agrees the ecology on twigs in the forest.

Growth inhibiting temperature: 35°C Lethal temperature: 40°C

12. ***Flavodon flavus*** (Klotzsch) Ryvarden (AN 98, GC 1285, GC 1369 & GC 1925): see fig. 9.

Very large spectrum with optimum situated between 30°C and 35°C. Encountered under dense vegetation cover as well as in semi-open habitats, this pantropical species should be able to withstand sun exposure and large temperature variations.

Growth inhibiting temperature: 50°C Lethal temperature: 50°C

13. ***Fomitopsis concava*** (Cooke) Cunn. (GC 1985): see fig. 9.

The single collection was made under dense vegetation cover. It presents a probable optimum between 25°C and 30°C and a strongly decreased growth rate at 35°C. With such a spectrum it should not be able to survive outside dense forest cover.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

14. ***Fomitopsis feei*** (Fr.) Kreisel (GC 470 & GC 1989): see fig. 9.

The spectrum shows a broad optimum between 20°C and 30°C. This type of spectrum is in agreement with the broad geographical distribution of this species extending into subtropical areas: it has been found in Central America, south America, in Southeast Asia, Australia and New Zealand.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

15. ***Fomitopsis rhodophaeus*** (Lév.) Imazeki (PDG 104): see fig. 9.

This fungus was collected in a relatively wet place protected from the sun. This explains perhaps the fact that the optimal temperature of growth is close to 30°C, the usual temperature in the forest. It must also be said that the growth of this strain is not very fast with a maximum growth rate reaching 831 ± 74 mm^2/day at 30°C.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

16. ***Ganoderma chalceum*** (Cooke) Steyaert (PDG 45, PDG 77 & PDG 123): see fig. 10.

First of all, it is noted that PDG 45 and PDG 77 have very similar spectra. Both have an optimum of growth at 30°C. This seems rather curious when the ecology of these two strains is studied: PDG 45 comes from a trunk beached, while PDG 77 was collected in the relatively open forest of the slopes of the Manam volcano.

PDG 123 shows the same broad characteristics but an optimum of growth at 25°C. PDG 123 was collected in a habitat with more vegetation cover than PDG 45 and PDG 77.

Growth inhibiting temperature: 35°C Lethal temperature: 45°C

17. *Ganoderma tornatum* (Pers.) Bres. (AN 43, AN 48, AN 50, GC 307 & GC 942): see fig. 11.

The 5 spectra obtained from the strains of this species are especially interesting for as in the preceding species those are some optima at 30°C and others at 25°C. It is difficult to interpret the very low growth of AN 43 compared to other strains. AN 48, AN 50 and GC 942 present an optimum at 30°C, while that of AN 43 and GC 307 are located at 25°C and that of GC 307 is located between 25°C and 30°C. It should be noted that Yen & Chen (1990) mentioned in Taiwan the existence of two groups[1] of *Ganoderma australe* (Fr.) Pat., of which one lives at low altitude generally showing an optimum of growth at 32°C and the other, in mountainous areas, with an optimum at 28°C and slower growth. AN 48 and AN 50 were collected on Laing Island, on the same trunk, while AN 43 comes from Boïsa Island which probably has higher humidity levels than Laing Island.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

18. *Gloeophyllum striatum* (Fr.) Murr. (PDG 57 & PDG 61): see fig. 6.

These two strains of the same species have a rather broad spectrum of growth with an optimum located between 30°C and 35°C. For PDG 61, little difference is observed between 25°C and 35°C. These two strains come from locations 100 meters apart. At the collection site, the incoming sea wind can cause a decrease in temperature of a few degrees in the Boroï river valley. Nonetheless, during the day *Rhizophora* is exposed to the sun, which could explain the width of the spectrum of this *Gloeophyllum*.

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

19. *Gloeoporus dichrous* (Fr.) Bres. (GC 94 & PDG 60): see fig. 8.

The two strains show a very broad spectrum with a very high growth at 15°C (± 500 mm^2/day). This type of spectrum agrees well with the subcosmopolitan character of this species. Nevertheless, the comparison of the two spectra suggests a certain variability within this species.

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

20. *Grammothele fuligo* (Berk. & Br.) Ryvarden (PDG 81 & PDG 88): see fig. 8.

The spectrum of these two strains is parallel at every point and, after taking into account the standard deviations, they are perfectly superposable. The spectrum of growth of *Grammothele fuligo* is very broad (between 15°C and 50°C). The optimum of growth is located at 35°C. This fits the ecology well, since these two strains come from very open places exposed to the sun during the day and a relative freshness during the night. Moreover, the basidiocarpe of these corticiaceous fungi (maximum 1 mm thickness) must be able to tolerate large temperature variations.

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

1. Ganoderma australe is actually a *nomen dubium*. Furhtermore, the descriptions of their description Yen & Chen (1990) would corresponds to *G. tornatum*.

21. ***Hexagonia apiaria*** (Pers.) Fr. (GC 376 & GC 1927): see fig. 1.

This species shows a very marked optimum at 30°C and a typical spectrum of tropical species confined to dense vegetation in an environment buffered against temperature variations. This spectrum is not in perfect agreement with the *in situ* observations, since this species was collected under both dense and open vegetation cover, which would suggest a growth at higher temperatures

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

22. ***Hexagonia speciosa*** Fr. (GC 1409): see fig. 1.

Optimum growth between 30°C and 35°C with a growth rate still high at 40°C. This spectrum agrees well for the habitat of this species found in open vegetation cover subject to large variations of temperature and moisture.

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

23. ***Hexagonia tenuis*** (Hook.) Fr. (AN 109, GC 137 & GC 290): see fig. 1.

The strains shows an optimum at 30°C and the spectra are similar for the two strains except that at 30°C, GC 137 has a growth rate close to 2000 mm_2/day, while for AN 109 the rate is close to 3000 mm_2/day. This spectrum agrees well with the habitat of this species found on branches and twigs under dense vegetation cover in an environment buffered against the temperature variations.

Growth inhibiting temperature: 40°C Lethal temperature: 40°C

24. ***Hypoxylon haematostroma*** Mont. (GC 36): see fig. 7.

Optimum at 30°C. The shape of the spectrum evokes that of a species growing on branches and twigs under dense vegetation cover.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

25. ***Lentinus concinnus*** Pat. (PDG 126): see fig. 13.

This strain has a broad growth spectrum with a maximum located between 30°C and 35°C. This collection was made on a large rotten stump in full sun. This species presents a very broad spectrum of growth. This type of spectrum is characteristic of tropical species growing in open habitats as well as under dense vegetation cover.

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

26. ***Lentinus squarrosulus*** Mont. (PDG 38, PDG 96, GC 18, GC 20, GC 336 & GC 407): see fig. 12

The four strains of *Lentinus squarrosulus* have a wide spectrum with a marked optimum at 35°C and a non negligible growth at 40°C. This spectrum implies that this species can withstand substantial temperature variations, which agrees with its occurrence under vegetation cover as well as in open habitats.

Growth inhibiting temperature: ≥ 45°C Lethal temperature: > 50°C

27. ***Lentinus strigosus*** (Schwein.) Fr. (GC 609): see fig. 13.

This species shows a very active growth in culture over a very broad range of temperatures, with a probable optimum at 40°C and a very significant growth between 25°C and 45°C. This is a standard spectrum for species with a very broad ecological amplitude.

Growth inhibiting temperature: > 45°C Lethal temperature: 50°C

28. ***Lenzites elegans*** (Spreng.: Fr.) Pat. (GC 84, GC 838 & GC 1923): see fig. 6.

Considering the very great standard deviation at 35°C, we can only say that the optimum is between 30°C and 35°C. It is astonishing to see that the temperature of inhibition is just 40°C, when this species is found under dense vegetation cover as well as in open habitats where such a temperature can easily occur. The lethal temperature is however at 50°C as in most species of open habitats.

Growth inhibiting temperature: 40°C Lethal temperature: 50°C

29. ***Microporellus obovatus*** (Jungh.) Ryvarden (GC 524): see fig. 13.

This species shows an optimum at 30°C and vigorous growth at 25°C, but almost no growth at 35°C. It shows a spectrum which in coastal forest should not enable it to grow outside of dense vegetation, which is the case for the two collections that we made. The high growth rate at 20°C and 25°C of this pantropical species must enable it to colonize cooler forests.

Growth inhibiting temperature: >35°C Lethal temperature: 40°C

30. ***Microporus affinis*** (Blume & Nees: Fr.) Kuntze (PDG 28, GC 61 & GC 510): see fig. 14.

This type of spectrum with a narrow optimum at 30°C also occurs in *Hexagonia tenuis* and *Microporus xanthopus* and seems characteristic for species growing on fallen branches and twigs under dense vegetation cover.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

31. ***Microporus xanthopus*** (Fr.) Kuntze (AN 24, AN 74, GC 1281, GC 1295 & GC 1388): see fig. 14.

As in *Hexagonia tenuis* and *Microporus affinis*, the spectrum of this species shows a very marked optimum at 30°C and an inhibiting temperature at 40°C, a spectrum that seems characteristic for species of fallen branches and twigs under dense vegetation cover.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

32. ***Phellinus adamantinus*** (Berk.) Ryvarden (GC 44): see fig. 15.

The low growth on malt agar of this strain can be explained by the fact that it is a parasitic species. The strain was collected on a living *Allophylus cobbe*. The optimum is at 30°C.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

33. ***Phellinus cesatii*** (Bres.) Ryvarden (GC 388): see fig. 15.

This species shows a spectrum of the same type as *Phellinus adamantinus*, but with a more marked optimum at 30°C. This species, which tolerates temperatures of 45°C, has been collected under dense vegetation cover and at the edge of a path in semi-open habitat.

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

34. ***Phellinus fastuosus*** (Lév.) Ryvarden (AN 27 & GC 353): see fig. 16.

It is difficult to explain the reduced growth (max. 14 mm^2/day) of this species that shows an optimum at 35°C typical of a tropical species. This species does not seem to be parasitic, which could explain such a slow growth on malt agar, since it was collected on *Intsia bijuga* dead for two years.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

35. ***Phellinus glaucescens*** (Petch) Ryvarden (GC 108): see fig. 15.

This strain shows a spectrum very similar to *Phellinus adamantinus* (GC 44) with an optimum at 30°C. It is however significant to mention its growth rate at 35°C and the absence of growth at 40°C. This probably enables it to support higher temperature variations than *Phellinus adamantinus,* even if our specimen, just like *Phellinus adamantinus* (GC 44), was collected under a very dense vegetation cover.

Growth inhibiting temperature: 45°C Lethal temperature: > 50°C

36. ***Phellinus linteus*** (Berk. & Curt.) Teng (AN 46 et AN 47): see fig. 16.

The same remark as for *Phellinus fastuosus* (AN 27) can be made for these the two strains, which also grow very slowly but with an optimum probably at a lower temperature (30°C).

Growth inhibiting temperature: 40°C Lethal temperature: 40°C

37. ***Phellinus melanodermus*** (Pat.) Fidalgo (GC 51): see fig. 15.

This species grows faster than the previous *Phellinus* and presents an optimum at 30°C, with a very significant growth at 20°C and 25°C. Little or no growth at 35°C would suggest this species was confined to dense vegetation cover. The collection was however made in a semi-open habitat.

Growth inhibiting temperature: 40°C Lethal temperature: 40°C

38. ***Phellinus merrillii*** (Murr.) Ryvarden (GC 455): see fig. 15.

Broad spectrum with an optimum at 30°C, and a good growth rate at 25°C and 35°C. The only collection was made in a semi-open habitat.

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

39. ***Phellinus noxius*** (Corner) Cunn. (AN 42): see fig. 15.

This is a fast growing species with an optimum at 30°C, but growth at 25°C is already very significant. The low growth at 35°C and lethal temperature of 40°C agree well with the collections under dense forest cover (on the root of a dead tree in the island of Boisa)

Growth inhibiting temperature: 40°C Lethal temperature: 40°C

40. *Phellinus senex* (Nees & Mont.) Imazeki (GC 30 et GC 75): see fig. 16.

The two strains of *Phellinus senex* are also fast growing and show a similar spectrum of growth with an optimum at 35°C, but no growth at 40°C. This species seems to develop especially under relatively dense vegetation cover.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

41. *Pleurotus djamor* (Fr.) Boedijn (GC 19, AN 78, GC 276 & GC 310): see fig. 17.

Optimum located at 30°C with good growth at 25°C and 20°C but almost none at 35°C. The shape of the spectrum is surprising considering the fact that our collections were made under covered habitats as well as in very exposed habitats, and this in all seasons. Nevertheless, this lack of resistance to high temperatures can be mitigated by a fast fructification of the mycelium. We observed for one of our collections the formation of a carpophore in less than 24 h. One could thus consider that mycelium located deep in the substratum and thus better preserved from heat strokes generated by sunlight can produce basidiomata in a short time during periods of lower sun exposure. GC 276 and GC 19 which come from a beached trunk show a lethality at 50°C whereas AN 78 which comes from Manam island, where the climate is probably cooler and moister than in Laing island, shows a lethality at 45°C.

Growth inhibiting temperature: 40°C Lethal temperature: ≥ 45°C

42. *Polyporus philippinensis* Berk. *sensu* Ryvarden (GC 21 & AN 34): see fig. 18.

The optimum of growth seems to be at 35°C but with a very great standard deviation. The shape of the graph resembles that of *Phellinus senex* (GC 30 and GC 75), but with a very weak growth as well as that of species colonising branches and twigs under dense vegetation cover, which is its ecology. The low growth is surprising for a coloniser of twigs where one would expect a faster growth to compete for this short lived habitat.

Growth inhibiting temperature: 40°C Lethal temperature: 40°C

43. *Polyporus squamosus* (Huds.: Fr.) Fr. (AN 18 & GC 112): see fig. 18.

More than the marked optimum at 30°C, it is the lethality at 35°C which appears atypical for a tropical species. This agrees with the opinion of Ryvarden & Johansen (1980) who consider *P. squamosus* as a subcosmopolitan species with a more or less reduced frequency in tropical regions. This spectrum implies that in tropical regions this species must be confined to very dense vegetation cover providing an environment buffered against temperature variations. It should be mentioned that this species like *P. philippinensis* has a very low growth rate.

Growth inhibiting temperature: 35°C Lethal temperature: 35°C

44. *Protomerulius africanus* (Ryvarden) Ryvarden (GC 638 & GC 1420): see fig. 8.

The spectrum of this species with an optimum at 25°C correlates well with the fact that we always collected it under dense vegetation cover, on the lower face of dead branches lying on the ground. These substrates had a moisture close to saturation and temperatures oscillating between 26°C and 28°C. It should be noted that while having an optimum at 25°C, this species can still growth at 15°C and 35°C.

Growth inhibiting temperature: ≥ 40°C Lethal temperature: 45°C

45. ***Pycnoporus sanguineus*** (L.: Fr.) Murrill (AN 94, GC 23, GC 67, GC 331, GC 605, GC 834, GC 919, GC 956 & GC 1002): see fig. 19.

This pantropical species collected in all seasons under dense vegetation cover as well as in the open and even in exposed zones at the edge of beaches (Castillo & Demoulin, 1997), shows *in vitro* a very vigorous growth over a wide range of temperatures, with an optimum at 35°C or 40°C according to the strains and a very substantial growth rate between 25°C and in most cases 45°C. This broad spectrum thus agrees with the broad ecology. Interestingly, the two strains (GC 331 and GC 605) with weak growth at 45°C come from mangrove habitats probably especially buffered against temperature and moisture variations.

Growth inhibiting temperature: > 50°C Lethal temperature: > 50°C

46. ***Rigidoporus catervatus*** (Berk.) Corner (GC 915 & GC1049): see fig. 20.

Collected three times and always under dense vegetation cover, this species shows an optimum located at 25°C, and almost no growth at 35°C. In tropical areas, this species should not be able to live outside of this type of forest. Its high growth rate at 25°C agrees well with its presence in cooler regions like New Zealand and Tasmania where it was cited by Cunningham (1965).

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

47. ***Rigidoporus defibulatus*** (Reid) Corner (GC 900): see fig. 20.

This species, showing a well marked optimum at 25°C, was collected only once, in a thermically well buffered forest.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

48. ***Rigidoporus* cf. *evolutus*** (Berk. & Curt.) Murrill (GC 678): see fig. 20.

Optimum well marked at 30°C with a high growth rate at 25°C and practically no growth at 35°C. With a spectrum of this type in the area studied, this species must be confined exclusively to areas under dense vegetation stet.

Growth inhibiting temperature: 40°C Lethal temperature: ≥40°C

49. ***Rigidoporus lineatus*** (Pers.) Ryvarden (GC 500): see fig. 20.

This strain shows a marked optimum at 30°C with almost no growth at 35°C.

Growth inhibiting temperature: 40°C Lethal temperature: ≥40°C

50. ***Rigidoporus microporus*** (Fr.) Overeem (GC 416): see fig. 20.

With its well marked optimum at 25°C, this species shows the spectrum of a species growing in dense forests. It was however also collected in clearings.

Growth inhibiting temperature: 35°C Lethal temperature: 45°C

51. *Rigidoporus vinctus* (Berk.) Ryvarden (GC 1984): see fig. 20.

Broad spectrum with an optimum at 30°C and good growth at 25°C and 35°C. We collected it only three times and each time under dense vegetation cover. This spectrum is adequate for a pantropical species extending into warm temperate areas (Ryvarden & Johansen, 1980).

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

52. *Schizophyllum commune* Fr.: Fr. (AN 131, PDG 24, PDG 92, GC 41 & GC 417): see fig. 21.

Very broad spectrum with an optimum at 35°C for AN 131 and GC 41 and 30°C for the others. It is a subcosmopolitan species but with a thermophilous character. The two most thermotolerant strains (GC 41 and AN 131) with optimum at 35°C and growth inhibiting temperature at 45°C both come from Laing Island, the other strains come from the forest on the mainland in the Ramu river area. It would be interesting to extend this study of possibly ecotypic variation to cultures coming from more temperate areas. An *in vitro* study of the influence of temperature and salinity on this species has been published by Castillo & Demoulin (1997).

Growth inhibiting temperature: 45 or 50°C Lethal temperature: 50°C

53. *Stereum lobatum* (Kuntze: Fr.) Fr. (GC 351): see fig. 8.

The well marked optimum at 30°C agrees well with its occurrence under dense vegetation cover in an environment buffered against temperature variations.

Growth inhibiting temperature: 35°C Lethal temperature: 40°C

54. *Trametes demoulinii* G. Castillo (GC 43 & GC 81): see fig. 22.

Marked optimum at 30°C. As with other species collected under dense vegetation cover, such as *Microporus affinis* (GC 61), *Auricularia* cf. *mesenterica* (GC 39 and GC 129) and others, *Trametes demoulinii* was collected in very dense undergrowth and always on very degraded and wet branches and twigs.

Growth inhibiting temperature: 40°C Lethal temperature: 45°C

55. *Trametes incana* Lév. (GC 940 & GC1901): see fig. 22.

This species with an optimum at 30°C shows a very broad spectrum and a high growth rate. This species was collected twice, always under dense vegetation cover. The broad spectrum agrees with the geographical distribution in a large area of Asia. This species has been reported by Ryvarden & johansen (1980) in India, Nepal, Sri Lanka, and the Philippines, and by Corner (1987) in Singapore and Malaysia, and by Zhao & Zhang (1992) in China.

Growth inhibiting temperature: 45°C Lethal temperature: 45°C

56. *Trametes lactinea* (Berk.) Pat. (AN 92 & GC 1978): see fig. 2.

Like *Pycnoporus sanguineus*, this species presents a very broad spectrum with an optimum between 35°C and 40°C; growth at 30°C and 45°C is also very close to the optimum.

Growth inhibiting temperature: 50°C Lethal temperature: 50°C

57. ***Trametes menziezii*** (Berk.) Ryvarden (PDG 63, VD 7498 & GC 56): see fig. 23.

Optimum at 35°C or 40°C. The growth at 45°C is very weak if one compares it with that of *Pycnoporus sanguineus*.

Growth inhibiting temperature: 50°C Lethal temperature: 50°C

58. ***Trametes microporoides*** Corner (GC 1900): see fig. 22.

This species collected under dense vegetation cover, shows in culture a very similar behaviour to that of *Trametes demoulinii* (cf 55).

Growth inhibiting temperature: 45°C Lethal temperature: ≥ 50°C

59. ***Trametes mimites*** (Wakef.) Ryvarden (GC 373): see fig. 23.

This species, morphologically very close to *Hexagonia tenuis* and very often confused with it, shows an optimum at 30°C with high growth rate at 25°C and 35°C. This species shows a typical behaviour for a species collected in semi-open habitats.

Growth inhibiting temperature: 45°C Lethal temperature: ≥ 50°C

60. ***Trametes pavonia*** (Hook.) Ryvarden (GC 401): see fig. 23.

Very broad spectrum with an optimum at 30°C. This spectrum agrees well with its probably pantropical distribution and the fact that it was found in a place exposed to strong temperature variation.

Growth inhibiting temperature: 50°C Lethal temperature: > 50°C

61. ***Trametes* cf. *pubescens*** (Schum.: Fr.) Pilát (AN 85, GC 442 & GC 1345): see fig. 2.

Optimum at 35°C but with vigorous growth at 30°C and 40°C. The growth at the lowest temperatures is of the same order of magnitude as for *Schizophyllum commune* (subcosmopolitan species). This could thus be the same species as in temperate areas, but the New Guinea material is slightly deviant morphologically.

Growth inhibiting temperature: 50°C Lethal temperature: 50°C

62. ***Trametes scabrosa*** (Pers.) Cunn. (AN 31, PDG 25, GC 22, GC 26, GC 33, GC 42, GC 47, GC 1287, GC 1326 & GC 1400): see fig. 24.

The species shows a broad optimum at 30°C, 35°C and 40°C according to the strains. Growth is always high at 30°C and often 40°C. This spectrum agrees well with the ecology of this pantropical species. It was sampled under dense vegetation cover or in zones exposed to direct sunlight. This variability between strains seems interesting, but we were unable to correlate the growth spectrum to the habitat where the collections were made.

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

63. ***Trametes scopulosa*** (Berk.) Bres. (AN 19): see fig. 22.

Little marked optimum at 35°C with near maximum growth at 30°C and 40°C. The very weak development at 20°C brings into question the identity of the taxon growing in tropical Asia, since the species described by Berkeley was collected at high altitude (Darjeeling).

Growth inhibiting temperature: 45°C Lethal temperature: 50°C

64. *Trametes villosa* (Swartz:Fr.) Kreisel (GC 837, GC 917 GC, 958, GC 1284, GC 1305, GC 1306, GC 1307, GC 1339 & GC 1342): see fig. 25.

The strains show a broad optimum varying according to the strains between 25°C and 40°C. This spectrum agrees well with the ecology of this species collected under dense vegetation cover as well as in zones exposed to direct insolation. From all the species for which several strains have been studied this is the one that shows the greatest ecotypic variation as to the optimum temperature for growth.

Growth inhibiting temperature: 50°C Lethal temperature: > 50°C

65. *Xylaria papyrifera* (Link) Fr. (GC 1068): see fig. 26.

Optimum apparently at 30°C, and growth rate practically nill at 35°C. This spectrum agrees well with the fact that this species was collected under dense vegetation cover in an environment buffered against temperature variations.

Growth inhibiting temperature: 35°C Lethal temperature: 50°C

66. *Xylocoremium hoffmannii* G.Castillo & Demoulin* (GC 76, GC 829 & GC 1067): see fig. 26.

* to be published

The optimum is apparently between 25°C and 30°C, according to the strains. With such a spectrum, this fungus, which is probably the imperfect stage of *Xylaria papyrifera,* must probably be confined to the undergrowth in an environment buffered against temperature variation.

Growth inhibiting temperature: 35°C Lethal temperature: 40°C

CONCLUSIONS

Our studies have showed a good relation correlation between the habitat observed in the field and the type of temperature-related growth spectrum of the species. The species collected under dense vegetation cover showed spectra with a very marked optimum at 30°C, and a strong reduction of growth rate if one deviates from this temperature (see fig. 1). This type of spectrum explains well the fact that they are only found under dense vegetation cover. Very typical species of this group are for instance: *Hexagonia tenuis, Microporus affinis, Microporus xanthopus, Stereum lobatum, Trametes demoulinii* and other rare species.

Several species, *Auricularia* cf. *mesenterica, Coriolopsis caperata, Daedalea sprucei, Hypoxylon haematostroma, Phellinus adamantinus, Phellinus melanodermus, Phellinus cesatii, Phellinus glaucescens, Polyporus squamosus, Rigidoporus lineatus, Xylaria papyrifera* and *Xylocoremium hoffmannii,* show a similar spectrum even if they are not specialised in the colonisation of fallen branches. They are probably linked to the same dense forest environment even if their substrates (logs, stumps) are less sensitive to environmental variation than branches.

We also observed that the species with a broad ecological amplitude, collected under both dense and open vegetation showed a spectrum with an optimum extending over a larger range of temperatures (see fig. 2). These species are *Coriolopsis floccosa, Coriolopsis polyzona, Flavodon flavus, Gloeophyllum striatum, Lentinus concinnus*, *Lentinus squarrosulus, Lentinus strigosus, Pycnoporus sanguineus, Schizophyllum commune, Trametes lactinea, Trametes menziezii, Trametes pavonia, Trametes scabrosa* and *Trametes villosa*.

It should be noted that intermediate spectra have been observed (figs 1, 4 & 5) which correspond to the majority of species found in semi-open habitats. These species are *Coriolopsis aspera*, *Coriolopsis* aff. *byrsina, Coriolopsis caperata, Coriolopsis floccosa* and *Hexagonia speciosa.*

We could observe two very opposite spectra for two subcosmopolitan species. On the one hand, *Polyporus squamosus* shows a very weak growth with a marked optimum at 30°C, but with a temperature of lethality equal to 35°C. This spectrum is atypical for a fungus growing in a tropical forest. On the other hand, *Gloeoporus dichrous* shows very vigorous growth and an optimum extending from 25°C to 35°C.

It is also worth to mention that our cultures are preserved at 4°C and that this temperature is lethal for none of them. At this temperature, only one strain (*Gloeoporus dichrous*: GC 94) showed a very weak growth, not easily quantifiable. The other strains have growth rates at 15°C ranging from 0 to 60 mm^2/day, while *Gloeoporus dichrous* presents a growth rate close to 500 mm^2/day and is thus the species best adapted to grow in a wide latitudinal area.

An interesting feature, which we will elaborate in future publications, is that the biodiversity of lignicolous fungi is higher in the core areas of the forests we studied. As the present study has established, many fungi found there showed a narrow ecological amplitude (of the 67 taxa sampled, 39 had weak or no growth at 40°C). They would not be able to grow in open habitats exposed to wide temperature variations , which are colonised by a limited number of species. Why these latter species, which apparently should be highly competitive, are not dominant inside forests is a fundamental question in the present debate on the biodiversity value of different ecosystems.

Acknowledgements. This research was supported by grants FRFC n° 2.9006.90, n° 2.4521.96 and 2.4551.99 of the Belgian National Fund for Scientific Research. Many thank to V. Salpeteur, F. Vandesteene, P. Georis, O. Schoebrechts and M. Corvisier who provided some cultures or helped the with the growth experiments.

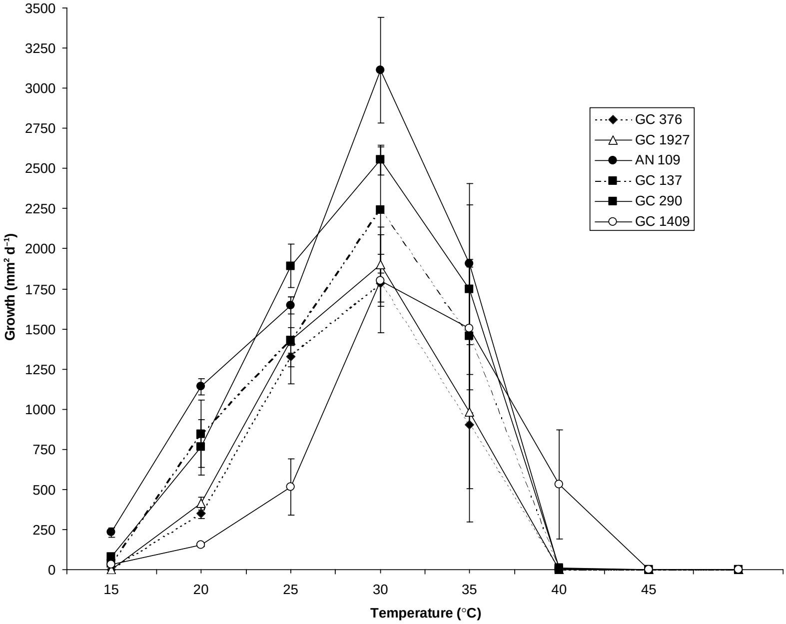

Fig. 1. Temperature effect on maximal growth rate of *Hexagonia apiaria* (GC 376 & GC1927), *Hexagonia speciosa* (GC 1409) and *Hexagonia tenuis* (AN 109, GC 137 & GC 290).

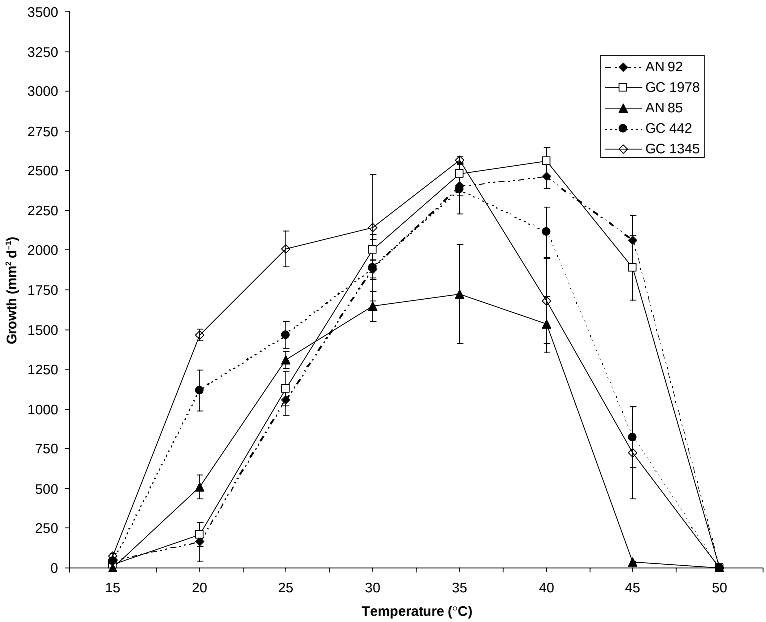

Fig. 2. Temperature effect on maximal growth rate of *Trametes lactinea* (AN 92 & GC 1978) and *Trametes* cf. *pubescens* (AN 85, GC 442 & GC 1345).

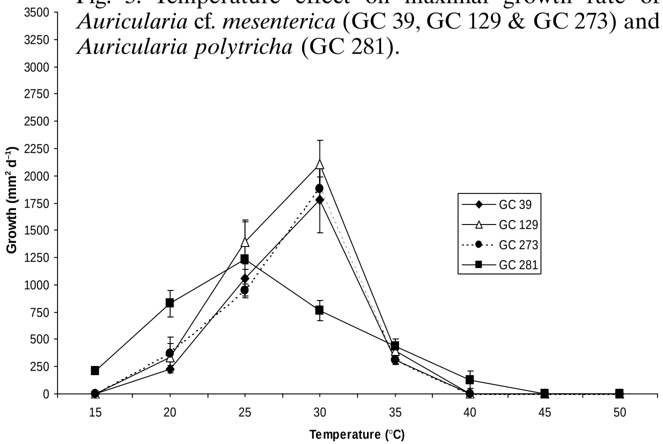

Fig. 3. Temperature effect on maximal growth rate of *Auricularia* cf. *mesenterica* (GC 39, GC 129 & GC 273) and *Auricularia polytricha* (GC 281).

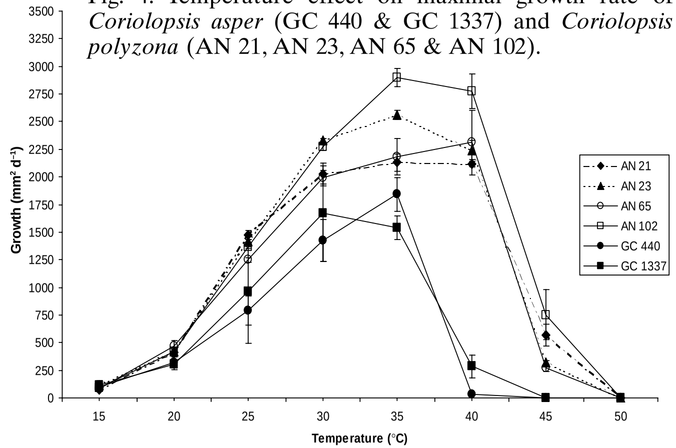

Fig. 4. Temperature effect on maximal growth rate of *Coriolopsis asper* (GC 440 & GC 1337) and *Coriolopsis polyzona* (AN 21, AN 23, AN 65 & AN 102).

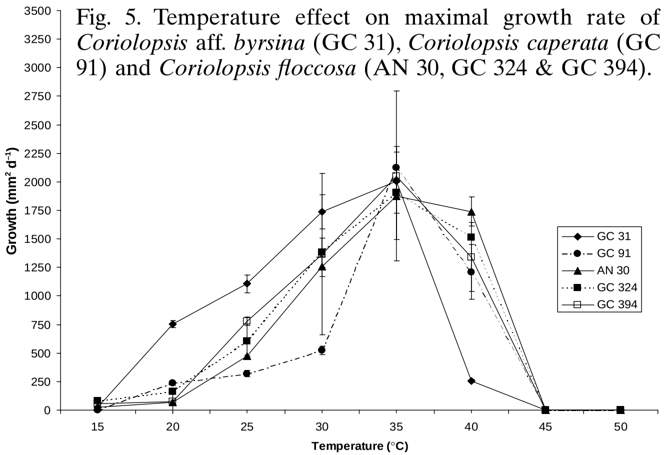

Fig. 5. Temperature effect on maximal growth rate of *Coriolopsis* aff. *byrsina* (GC 31), *Coriolopsis caperata* (GC 91) and *Coriolopsis floccosa* (AN 30, GC 324 & GC 394).

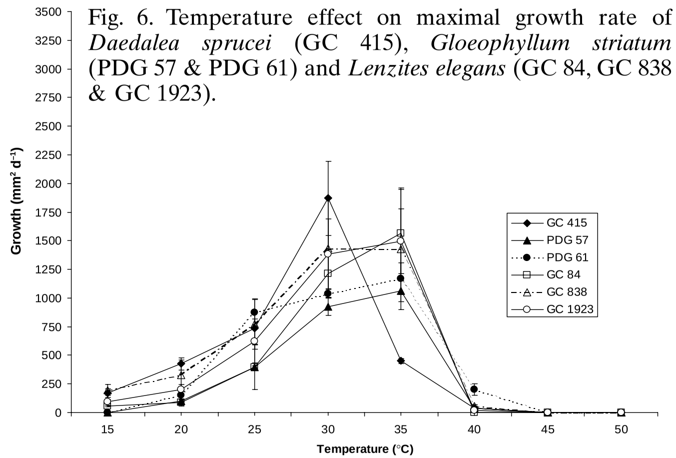

Fig. 6. Temperature effect on maximal growth rate of *Daedalea sprucei* (GC 415), *Gloeophyllum striatum* (PDG 57 & PDG 61) and *Lenzites elegans* (GC 84, GC 838 & GC 1923).

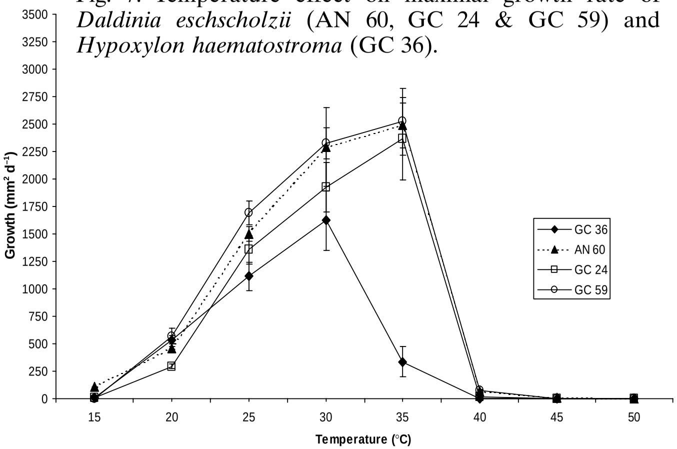

Fig. 7. Temperature effect on maximal growth rate of *Daldinia eschscholzii* (AN 60, GC 24 & GC 59) and *Hypoxylon haematostroma* (GC 36).

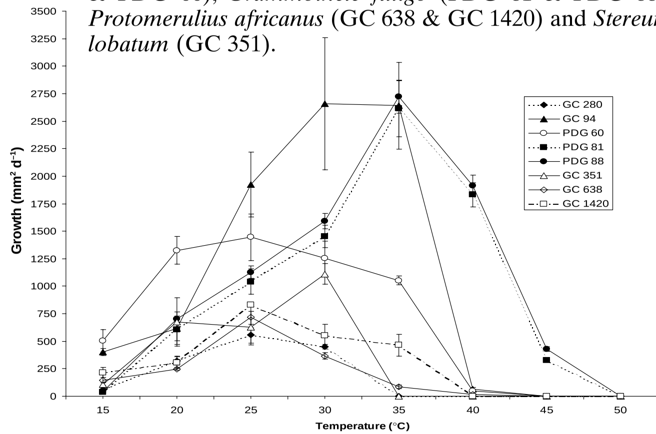

Fig. 8. Temperature effect on maximal growth rate of *Epithele laingiana* (GC 280), *Gloeoporus dichrous* (GC 94 & PDG 60), *Grammothele fuligo* (PDG 81 & PDG 88), *Protomerulius africanus* (GC 638 & GC 1420) and *Stereum lobatum* (GC 351).

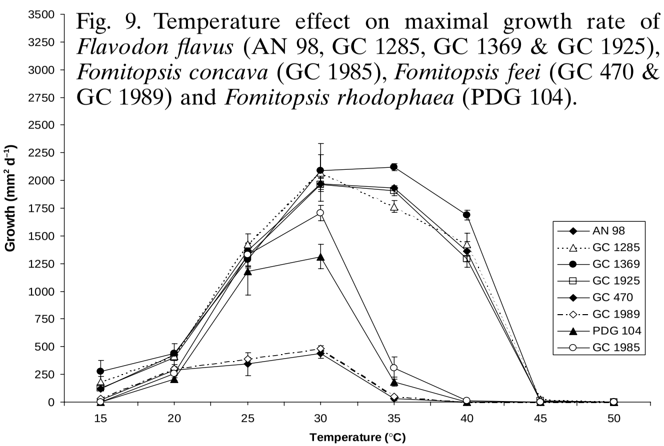

Fig. 9. Temperature effect on maximal growth rate of *Flavodon flavus* (AN 98, GC 1285, GC 1369 & GC 1925), *Fomitopsis concava* (GC 1985), *Fomitopsis feei* (GC 470 & GC 1989) and *Fomitopsis rhodophaea* (PDG 104).

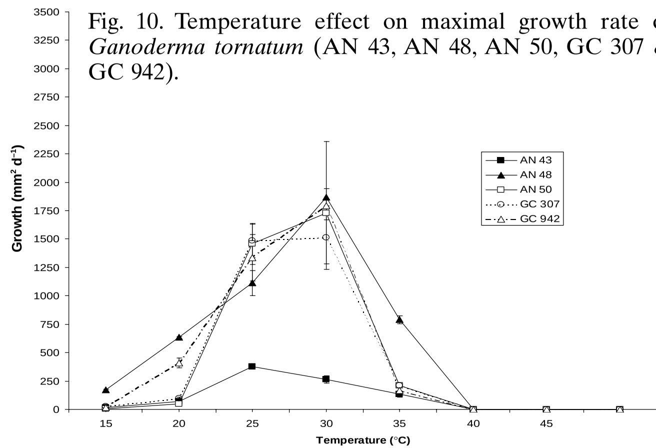

Fig. 10. Temperature effect on maximal growth rate of *Ganoderma tornatum* (AN 43, AN 48, AN 50, GC 307 & GC 942).

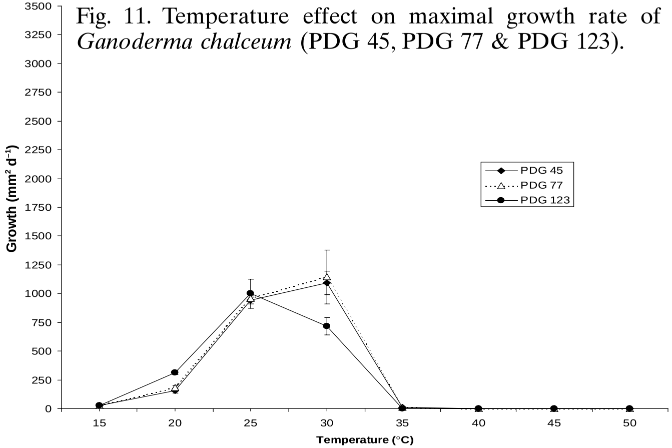

Fig. 11. Temperature effect on maximal growth rate of *Ganoderma chalceum* (PDG 45, PDG 77 & PDG 123).

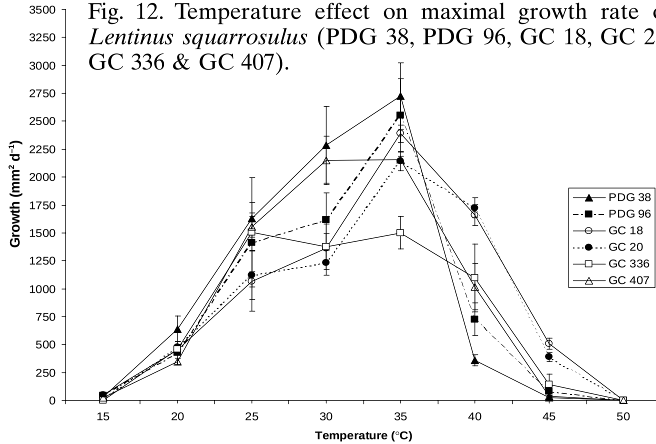

Fig. 12. Temperature effect on maximal growth rate of *Lentinus squarrosulus* (PDG 38, PDG 96, GC 18, GC 20, GC 336 & GC 407).

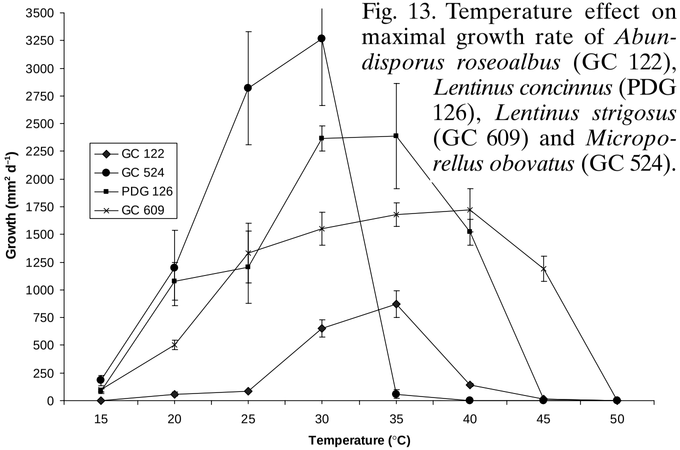

Fig. 13. Temperature effect on maximal growth rate of *Abundisporus roseoalbus* (GC 122), *Lentinus concinnus* (PDG 126), *Lentinus strigosus* (GC 609) and *Microporellus obovatus* (GC 524).

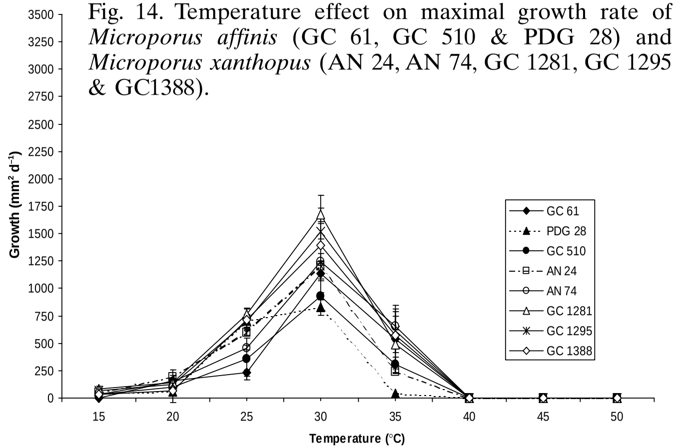

Fig. 14. Temperature effect on maximal growth rate of *Microporus affinis* (GC 61, GC 510 & PDG 28) and *Microporus xanthopus* (AN 24, AN 74, GC 1281, GC 1295 & GC1388).

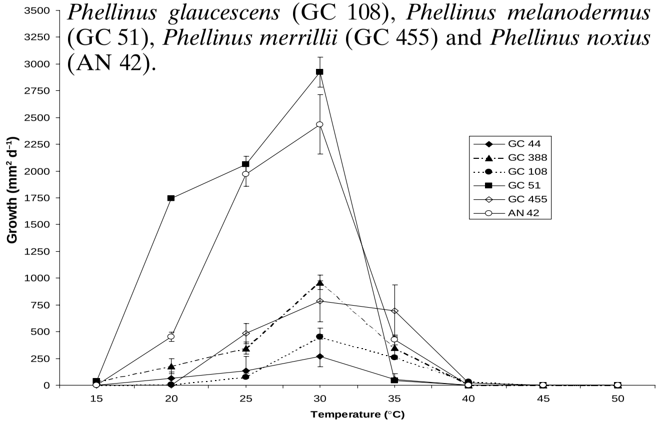

Fig. 15. Temperature effect on maximal growth rate of *Phellinus adamantinus* (GC 44), *Phellinus cesatii* (GC 388), *Phellinus glaucescens* (GC 108), *Phellinus melanodermus* (GC 51), *Phellinus merrillii* (GC 455) and *Phellinus noxius* (AN 42).

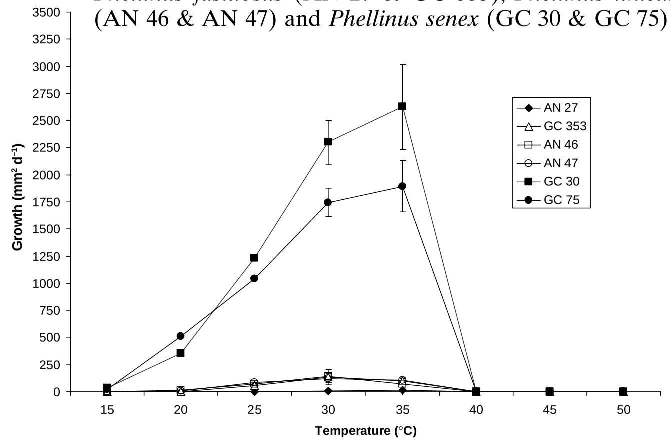

Fig. 16. Temperature effect on maximal growth rate of *Phellinus fastuosus* (AN 27 & GC 353), *Phellinus linteus* (AN 46 & AN 47) and *Phellinus senex* (GC 30 & GC 75).

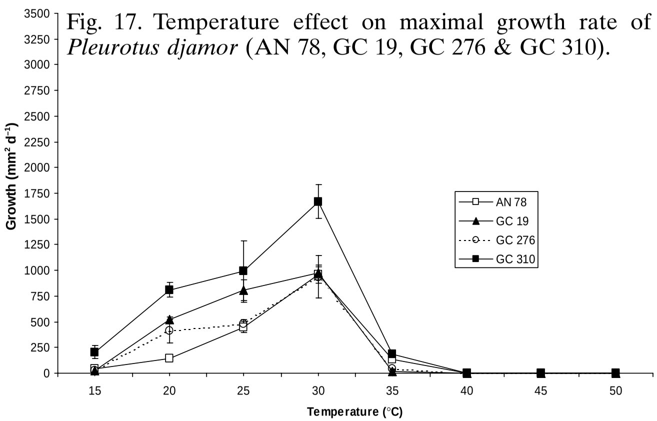

Fig. 17. Temperature effect on maximal growth rate of *Pleurotus djamor* (AN 78, GC 19, GC 276 & GC 310).

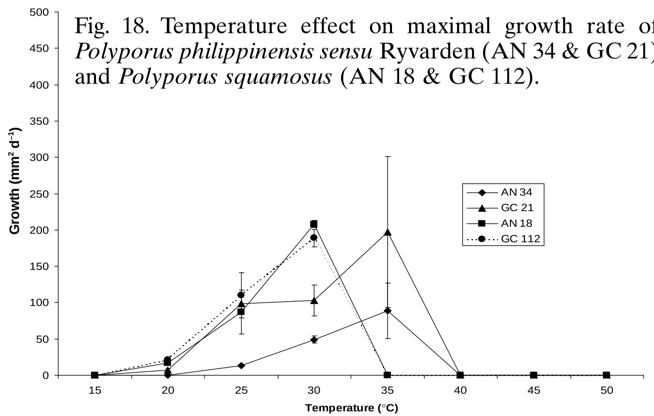

Fig. 18. Temperature effect on maximal growth rate of *Polyporus philippinensis sensu* Ryvarden (AN 34 & GC 21) and *Polyporus squamosus* (AN 18 & GC 112).

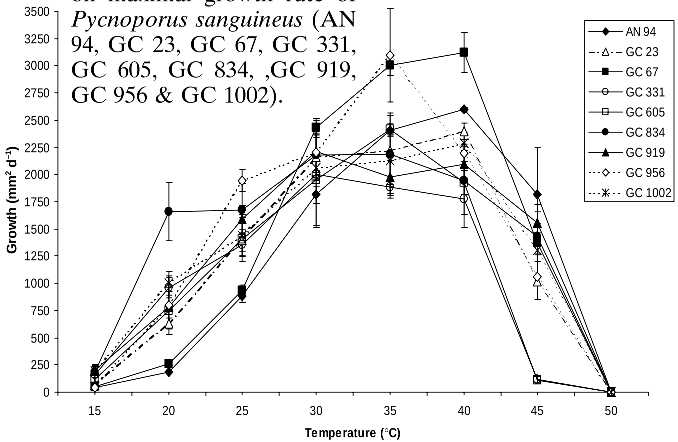

Fig. 19. Temperature effect on maximal growth rate of *Pycnoporus sanguineus* (AN 94, GC 23, GC 67, GC 331, GC 605, GC 834, ,GC 919, GC 956 & GC 1002).

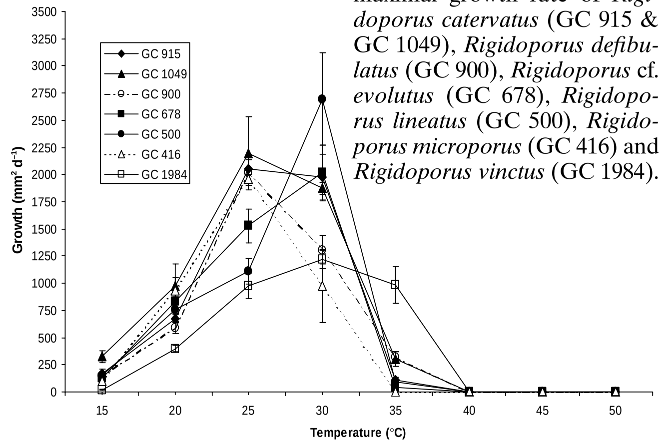

Fig. 20. Temperature effect on maximal growth rate of *Rigidoporus catervatus* (GC 915 & GC 1049), *Rigidoporus defibulatus* (GC 900), *Rigidoporus* cf. *evolutus* (GC 678), *Rigidoporus lineatus* (GC 500), *Rigidoporus microporus* (GC 416) and *Rigidoporus vinctus* (GC 1984).

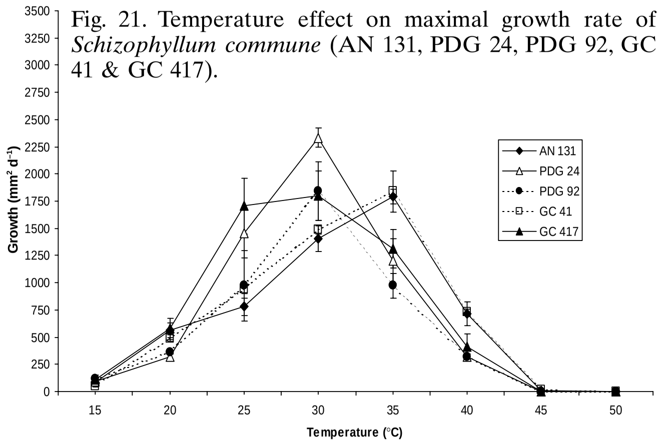

Fig. 21. Temperature effect on maximal growth rate of *Schizophyllum commune* (AN 131, PDG 24, PDG 92, GC 41 & GC 417).

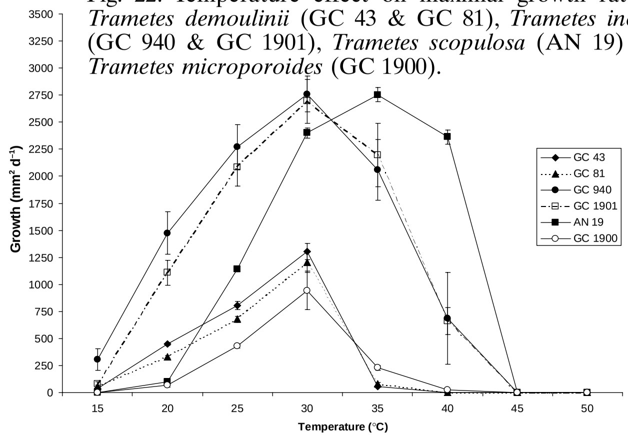

Fig. 22. Temperature effect on maximal growth rate of *Trametes demoulinii* (GC 43 & GC 81), *Trametes incana* (GC 940 & GC 1901), *Trametes scopulosa* (AN 19) and *Trametes microporoides* (GC 1900).

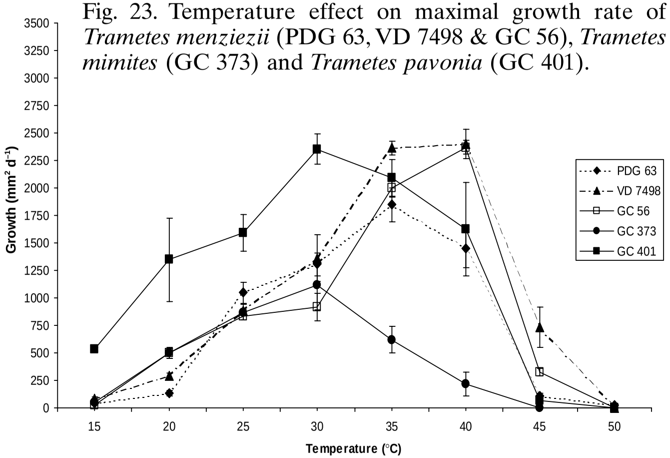

Fig. 23. Temperature effect on maximal growth rate of *Trametes menziezii* (PDG 63, VD 7498 & GC 56), *Trametes mimites* (GC 373) and *Trametes pavonia* (GC 401).

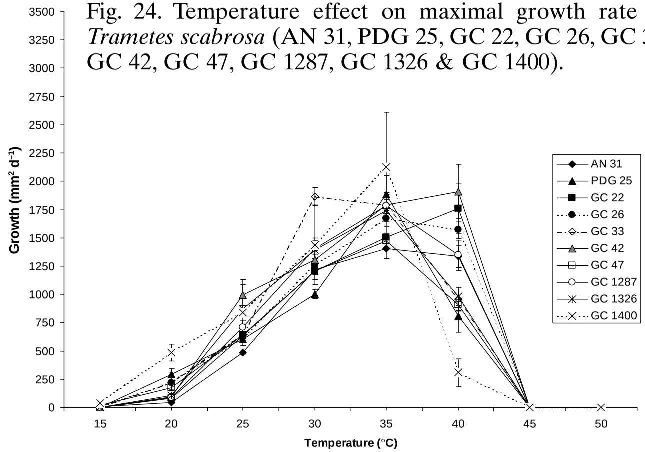

Fig. 24. Temperature effect on maximal growth rate of *Trametes scabrosa* (AN 31, PDG 25, GC 22, GC 26, GC 33, GC 42, GC 47, GC 1287, GC 1326 & GC 1400).

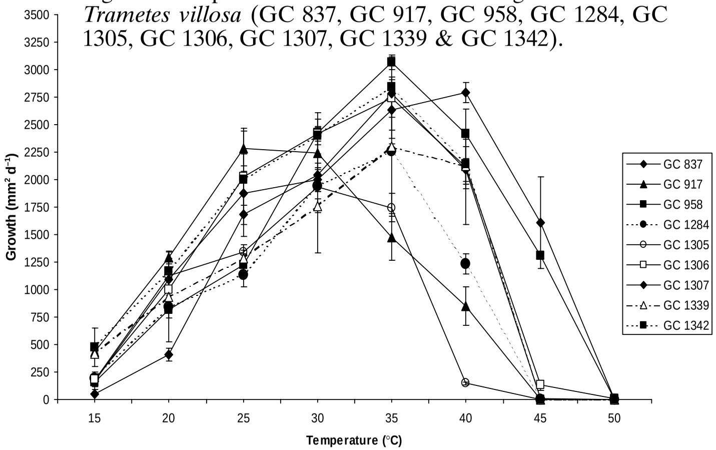

Fig. 25. Temperature effect on maximal growth rate of *Trametes villosa* (GC 837, GC 917, GC 958, GC 1284, GC 1305, GC 1306, GC 1307, GC 1339 & GC 1342).

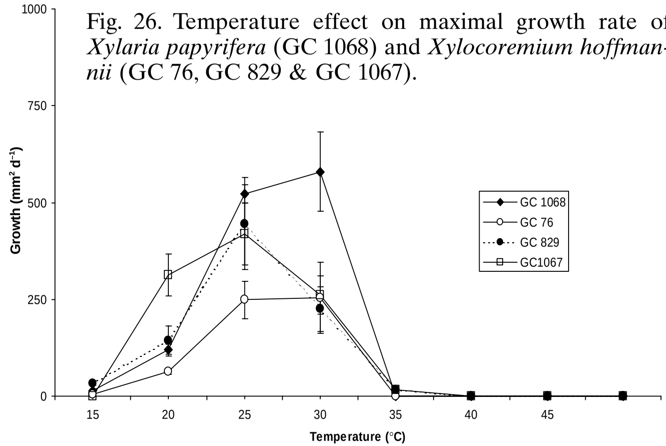

Fig. 26. Temperature effect on maximal growth rate of *Xylaria papyrifera* (GC 1068) and *Xylocoremium hoffmannii* (GC 76, GC 829 & GC 1067).

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