Temperature and relative humidity in a palaeontological collection: the buffering effect of microenvironments

Température et humidité relative dans une Collection Paléontologique: l'effet tampon des microclimats

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ABSTRACT

Adequate values of environmental parameters are crucial for the long term preservation of the fossils in a palaeontological collection. In particular, incorrect or fluctuating temperature (T) and relative humidity (RH) can affect glued or repaired materials, induce the proliferation of mould, provoke mechanical breakage, recrystallization or mineral decay. From April 2015 to March 2017, six hygrothermometers were incorporated in selected microenvironments of the Palaeontological Collection at the Facultad de Ciencias, Universidad de la República at Montevideo, Uruguay. The main aim of this study was to test the buffering effect of different enclosures compared to the ambient environmental parameters (AMB). The selected storage units were a mobile rack of shelves (C1), a cardboard box inside C1 (C2), a lidded plastic polypropylene box inside C1 (C3), a drawer in a non sealed cabinet (P), and a drawer inside a tightly sealing cabinet (G1). Maximum and minimum values of T and RH were manually gathered on a weekly basis. Linear graphs and statistical analysis (i.e. mean values, standard deviation and Kruskall-Wallis non-parametric variance analysis) were used to compare the measurements obtained. Regarding both T and RH, the more extreme values and fluctuation of these parameters were achieved in the ambient. With respect to T, all enclosures protected from Tmax variations as lower Tmax were recorded inside enclosures. With respect to RH, only C3 and G1 showed significantly lower values of RHmax than ambient values. Additionally, C3 and G1 showed an almost constant amplitude between maximum and minimum values which indicates that specimens were less exposed to fluctuations in RH. The results herein obtained show that to minimize the impact of environmental instability, it is safer for specimens to substitute cardboard by plastic containers, and closed storage units are better than open ones. In addition, sealed containers and cabinets protect the specimens from other agents of deterioration such as dust and pests.

RÉSUMÉ

Des valeurs adéquates des paramètres environnementaux sont cruciales pour la conservation à long terme des fossiles dans une collection paléontologique. Une température (T) et une humidité relative (HR) incorrectes ou fluctuantes peuvent affecter les matériaux collés ou réparés, provoquer la prolifération de moisissures, produire une rupture mécanique, une recristallisation ou une décomposition minérale. Pendant la période d’avril 2015 à mars 2017, six hygrothermomètres ont été incorporés dans des microclimats sélectionnés de la collection paléontologique de la Facultad de Ciencias, Universidad de la República à Montévideo, Uruguay. L’objectif principal était de tester l’effet tampon de différentes enceintes par rapport aux paramètres climatiques environnants. Deux parmi les quatre unités de stockage sélectionnées étaient rangées sur une étagère mobile à plusieurs rayons (C1), une boîte en carton (C2), et une boîte en plastique en polypropylène avec couvercle (C3). Deux autres étaient un tiroir dans une armoire non scellée (P) et un tiroir à l'intérieur d'une armoire hermétique (G1). Les valeurs maximales et minimales de T et HR ont été collectées manuellement une fois par semaine. Des graphiques linéaires issus de l'analyse statistique (valeurs moyennes, écart-type et analyse de la variance non paramétrique de Kruskall-Wallis) ont été utilisés pour comparer les mesures obtenues. En ce qui concerne à la fois T et HR, les fluctuations les plus extrêmes de ces paramètres ont été atteintes dans l'environnement. En ce qui concerne T, toutes les enceintes protégées contre les variations de Tmax, en tant que inférieures à Tmax, ont été enregistrées à l'intérieur de toutes les enceintes. Concernant HR, seuls C3 et G1 ont montré des valeurs de HRmax significativement inférieures aux valeurs ambiantes. De plus, les enceintes C3 et G1 ont montré une amplitude presque constante entre les valeurs maximales et minimales, ce qui indique que les échantillons étaient moins exposés aux fluctuations d'humidité relative. Les résultats obtenus ici montrent que pour minimiser l'impact de l'instabilité environnementale, il est plus sûr pour les spécimens de remplacer le carton par des récipients en plastique, et les unités de stockage fermées sont meilleures que les unités ouvertes. De plus, des récipients et des armoires scellés protègent les échantillons contre d'autres agents de détérioration tels que la poussière et les parasites.

Keywords: fossils, enclosures, temperature, relative humidity, Uruguay

Mots clés: fossiles, enceintes, température, humidité relative, Uruguay

1. Introduction

In preventive conservation studies, inadequate temperature and relative humidity conditions are well known agents of deterioration, that can affect different types of collections (e.g., Rose and Hawks, 1995; Waller, 1994, 1995; Simmons and Muñoz-Saba, 2003). A general debate on the environmental conditions to guarantee the long term preservation of diverse kinds of objects has been taking place in the conservation community (e.g., Michalski, 1993, 1996, 2016; Ashley-Smith, 1999; Atkinson, 2014; Bickersteth, 2014). Historically, numerical values around 50% to 55% relative humidity and a temperature of about 20ºC is advised for many types of objects (see review by Atkinson, 2014). However, these conditions may be expensive to maintain, and require the use of a large amount of energy supply. Taking this into account, there has been a tendency to soften the strict environmental limits to a more low energy cost adjusted to local or regional climates, but still considering the long term conservation of collections. This discussion is predominantly but not exclusively focused in art or cultural collections (i.e., AIC Environmental Guidelines, 2013). For example, for several kinds of objects containing hygroscopic material (mostly paintings, textiles, ethnographic objects or animal glue) a stable relative humidity in the range of 40% to 60%, and temperature in the range 16ºC - 25ºC is required (see National Museums Director's Conference, 2009; Bickersteth, 2016). However, more sensitive objects will require specific and tighter RH and T control (e.g., Mecklenburg and Tumosa, 1999; Michalski, 2016).

Regarding the preservation of geological collections, some authors point out that specific guidelines for their care are insufficient or contradictory (see Baars and Horak, 2018). Specifically, palaeontological specimens are thought to be more resistant than other types of natural history objects, although it has been established that fossils are susceptible to agents of deterioration (Howie, 1979). Most research has been focused on pyritised fossils and enclosing rocks, such as shales containing pyrite or those included in amber (e.g. Howie, 1979; Newman, 1998; Fellowes and Hagan, 2003; Odin et al., 2014). Accelerated ageing applied to fossil specimens or fossil bearing rocks suggested that an ambient of stable humidity, low temperature and low light exposure are required for their correct preservation (Bisulca et al., 2012; Odin et al., 2014).

Fossils that have been repaired, coated or impregnated with a variety of consolidants (sometimes known and sometimes unknown due to the lack of documentation) may be more vulnerable to shifting environmental parameters (Howie, 1984). Non-optimal relative humidity and temperature may have indirect effects on specimens, such as the proliferation of mould, acid generation, breakage due to dimensional instability (contraction / expansion), recrystallisation, mineral decay or desiccation (Montero and Diéguez, 1997; Green, 2001). Those effects may occur at a RH around 70% and can affect not only specimens but also labels and cabinets.

The specimens housed in the Palaeontological Collection (FCDP) at the Facultad de Ciencias, Universidad de la República in the city of Montevideo, Uruguay, correspond to microfossil, ichnofossils, fossil invertebrate, fossil vertebrate and few palaeobotanical specimens. Rojas (2011) described the state of the art of the collection and the starting activities for its proper management and care. Among these, the storage enhancement and the monitoring of T and RH in the collection were two of the actions taken towards the long-term preservation of the fossil specimens. The initial environmental monitoring was pursued as a diagnosis of the conditions in two of the collection cabinets, because of the lack of a permanent system of environmental buffering from the exterior medium. In addition, the multiple use of the collection room as sample repository, fossil preparation laboratory, and equipment storage area difficult the desirable isolation of the Collection. The preliminary results obtained indicated that the conditions were not optimum, especially in terms of RH but a more detailed environmental diagnosis was needed before specific interventions were decided (Rojas, 2011).

So far, no targeted studies have been carried out to empirically identify degradation caused by incorrect environmental conditions in our specimens. Despite this, during the sustained curation activities no evident damage as the described above or others, such as Byne's disease have been found on our specimens. However, being aware of the detrimental effects caused by inadequate conditions of T and RH on fossils, continuous efforts have been made towards preventing their appearance. In the last few years, several hygrothermometers were installed in selected locations of the collection, including the ambient and different storage units, such one of new tightly sealing cabinets acquired (see Rojas et al., 2013). As pointed out by Weintraub and Wolf (1995a), data on environmental monitoring have little value if they are not used. Thus, the aims of this contribution are: a) to compare the record of environmental parameters in different microenvironments of the palaeontological collection to the ambient, b) to evaluate the efficiency of the different enclosures in the buffering of temperature and relative humidity fluctuations, and c) to discuss the long term preservation of the fossil specimens in the different storage units.

2. Materials and Methods

2.1. Monitoring devices and locations

The Palaeontological Collection room is located at the building's periphery, has an area of 95 m^2 and is accessed by one door. It communicates to a semi-enclosed yard through several adjacent windows, which occupy the entire length of the room's west wall.

Six hygrothermometers were located in different locations within the room, monitoring the ambient and selected cabinet's T and RH conditions (Fig. 1). The ambient device (AMB) was located in the middle of the room resting on an open shelf (Fig. 1a). The remaining hygrothermometers were located in different places in order to record the microenvironments around the specimens. Three of them were situated inside a mobile not tightly sealed modular rack of shelves where medium and large sized fossil vertebrate specimens are stored: one was resting on a shelf (C1) (Fig. 1c), other was inside a cardboard box (C2) (Fig. 1d), and the remaining was inside a lidded transparent polypropylene plastic box (C3) (Fig. 1c). Another hygrothermometer rested inside a drawer of a fossil invertebrate cabinet with no doors located near a window (P) (Fig. 1b), and the last one was inside a drawer of a sealed cabinet with gasketed doors containing small to medium sized fossil vertebrates (G1) (Fig. 1e).

[Fig. 1 near here]

The monitoring devices used correspond to Kendo ETP101 hygrothermometers (temperature resolution: 0.1ºC; relative humidity resolution: 1%) that take measurements every 10 seconds. These are non-recording digital devices that store minimum and maximum values of temperature and relative humidity. The data were manually gathered on a weekly basis from the beginning of April 2015 to the end of March 2017, comprising a two year measurements time span.

2.2. Data analyses

Statistical analyses were performed in order to evaluate the results obtained for the different hygrothermometers in each location. Also, to test the buffering effect of the microenvironments in which the fossils are stored in the collection.

Temperature (T) and relative humidity (RH) linear graphs were constructed to provide a visually useful idea of the variation of the parameters in each location. They were constructed for each hygrothermometer compared to the ambient (AMB).

With the aim of testing if the variation of temperature and relative humidity in each storage unit was significantly different from the ambient, a variance analysis was performed. Tests for normal distribution and homoscedasticity of the data preceded by means of the Shapiro-Wilks test for normality and Levene's test for homocedasticity. Afterwards, the non parametric Kruskal-Wallis test was applied. Significance at a p-value of 0.05 was considered.

Basic statistics calculated were the mean and standard deviation for each measurement. With these data, box plots were used as an easy way to visualize the dispersion of T and RH values for each container. These were constructed considering the mean and standard deviation of each parameter per season. Measurements were grouped seasonally within the two years sampling: autumn (22nd March to the 21st June), winter (22nd June to the 21st September), spring (22nd September to the 21st December), and summer (22nd December to the 21st March).

Finally, the frequencies of different measurement ranges for each parameter were considered in order to detect the more prevalent environmental conditions in the storage units. For temperature, ranges of 2ºC were established, while for relative humidity ranges of 10% were used.

The software Excel, Past (Hammer et al., 2001) and Gnumeric (The Gnome Project, 2015) were used for the statistical analyses.

3. Results

3.1. Temperature conditions

Temperature graphs showed a seasonal variation with higher Tmax and Tmin during the summer measurements and lower values during winter (Fig. 2). The highest variation between the enclosures and the ambient record was in Tmax values (Fig. 2b-f). Tmin values showed less variation (Fig. 2b-f). All enclosures experienced significantly lower Tmax values than the AMB (Table 1). On the contrary, Tmin measurements obtained for the enclosures were not significantly different from those of the AMB (Table 2).

[Fig. 2 near here]

Table 1. Kruskal – Wallis test for maximum temperature (Tmax) values H (Chi^2) = 67.8; Hc (tie corrected) = 67.82; p_{same} = 2.906E-13. Mann-Whitney pairwise comparisons, Bonferroni corrected (below diagonal) \ uncorrected (above diagonal). Bold numbers indicate statistically significant differences at a p-value of 0.05.

Test de Kruskal - Wallis pour les valeurs de température maximales (Tmax) H (Chi^2) = 67,8; Hc (corrigé) = 67,82; p_{same} = 2.906E-13. Comparaisons par paires de Mann-Whitney, Bonferroni corrigé (en dessous de la diagonale) \ non corrigé (au-dessus de la diagonale). Les chiffres en gras indiquent des différences statistiquement significatives à une valeur de p de 0.05.

	C1 Tmax	C2 Tmax	C3 Tmax	P Tmax	G1 Tmax	Amb Tmax
C1 Tmax	0	**0.02705**	**0.01139**	**0.03288**	0.4869	**2.62E-06**
C2 Tmax	0.4057	0	0.7408	**6.98E-05**	**0.003826**	**9.02E-10**
C3 Tmax	0.1709	1	0	**9.79E-06**	**0.001155**	**9.40E-11**
P Tmax	0.4932	**0.001046**	**0.0001468**	0	0.1086	**0.002036**
G1 Tmax	1	0.05739	**0.01733**	1	0	**1.04E-05**
Amb Tmax	**3.92E-05**	**1.35E-08**	**1.41E-09**	**0.03054**	**0.0001556**	0

Table 2. Kruskal – Wallis test for minimum temperature (Tmin) values H (Chi^2) = 6.8; Hc (tie corrected) = 6.804; p_{same} = 0.2357. Mann-Whitney pairwise comparisons, Bonferroni corrected (below diagonal) \ uncorrected (above diagonal).

Test de Kruskal - Wallis pour les valeurs de température minimales (Tmin) H (Chi^2) = 6,8; Hc (corrigé) = 6,804; p_{same} = 0.2357. Comparaisons par paires de Mann-Whitney, Bonferroni corrigé (en dessous de la diagonale) \ non corrigé (au-dessus de la diagonale).

	C1 Tmin	C2 Tmin	C3 Tmin	P Tmin	G1 Tmin	Amb Tmin
C1 Tmin	0	0.3662	0.4565	0.5451	0.259	0.3805
C2 Tmin	1	0	0.8725	0.8087	0.05743	0.1089
C3 Tmin	1	1	0	0.9372	0.07295	0.1188
P Tmin	1	1	1	0	0.1038	0.1627
G1 Tmin	1	0.8614	1	1	0	0.8648
Amb Tmin	1	1	1	1	1	0

Temperature box-plots showed the mean and standard deviation seasonally through the time interval analysed (Fig. 3). The AMB box-plots depicted the highest dispersion of values as means varied in the different seasons and whiskers are long (except in the summer 2016-2017). In addition, a higher mean temperature is evident for the AMB during the winter of 2016 (Fig. 3a). C1, C2, and C3 box-plots show a similar distribution of mean and standard deviation although C1 has slightly higher dispersion, while C2 boxes are more homogeneously distributed (Fig. 3b,c,d). P box-plots show a general similar distribution as the AMB (except during the summer 2015-2016), but whiskers are shorter (Fig. 3e). G1 boxplot's show a similar but attenuated trend to those of the AMB and P, also displaying lower dispersion values (Fig. 3f).

[Fig. 3 near here]

Regarding the ranges of maximum temperature most frequently recorded in each container, only the AMB reached the highest values (29ºC - 30.9ºC) although in a very low frequency (Fig. 4a). Also, more than 70% of the time, this location experienced temperatures between 23ºC and 26.9ºC. Although P recorded up to 35% of the time span considered a temperature between 21ºC and 22.9ºC, the ranges 25ºC - 26.9ºC and 23ºC - 24.9ºC were represented during 60% of the time. C1 showed a similar distribution of frequencies as P, but recording an almost 45% in the latest mentioned ranges. C2 and C3 were very much alike with almost 90% of the time interval between 19ºC and 24.9ºC. Finally, G1 showed a 45% peak of records in the range 21ºC - 22.9ºC but with similar higher than 20% frequency in the ranges 23ºC - 24.9ºC and 25ºC - 26.9ºC.

Minimum temperature frequencies showed a more homogeneous distribution among storage units (Fig. 4b). All enclosures and AMB recorded Tmin more frequently in the range 19ºC - 20.9ºC, and secondary in the 23ºC - 24.9ºC range. G1 was the microenvironment that showed the more similar distribution to the AMB, while C2 and P behaved similarly as well.

[Fig. 4 near here]

3.2. Relative humidity conditions

Ambient relative humidity was highly variable both in RHmax and RHmin, as well as the weekly amplitude between both values (Fig. 5). Unlike temperature, no clear seasonal pattern was observed, and pronounced peaks and drops in RH were detected along the lapse considered. The highest RHmax recorded reached 90% and the lowest RHmin value was 32%. The weekly difference between RHmax and RHmin was about 30% most of the time.

[Fig. 5 near here]

In the storage units considered, different conditions were found (Fig. 5b-f). The containers C1, C2 and P showed roughly similar RH tendencies in relation to AMB (Fig. 5b,c,e). Regarding RHmax, these containers recorded lower values than the AMB during most of the time interval considered. Exceptions were in C1 during part of winter and spring 2016, and C2 especially during part of the autumn 2016. However, the statistical analysis by means of the Kruskal-Wallis test indicates that the differences in RHmax values were not significant for C1, C2, and P (Table 3).

Table 3. Kruskal – Wallis test for maximum relative humidity (RHmax) values H (Chi^2) = 87.66; Hc (tie corrected) = 87.81; p_{same} = 1.934E-17. Mann-Whitney pairwise comparisons, Bonferroni corrected (below diagonal) \ uncorrected (above diagonal). Bold numbers indicate statistically significant differences at a p-value of 0.05.

Test de Kruskal - Wallis pour les valeurs maximales d'humidité relative (RHmax) H (Chi^2) = 87.66; Hc (corrigé) = 87.81; p_{same} = 1.934E-17. Comparaisons par paires de Mann-Whitney, Bonferroni corrigé (en dessous de la diagonale) \ non corrigé (au- dessus de la diagonale). Les chiffres en gras indiquent des différences statistiquement significatives à une valeur de p de 0.05.

	C1 RHmax	C2 RHmax	C3 RHmax	P RHmax	G1 RHmax	Amb RHmax
C1 RHmax	0	0.9787	**1.09E-05**	0.1865	**9.33E-11**	0.2679
C2 RHmax	1	0	**5.66E-05**	0.1177	**3.57E-10**	0.2745
C3 RHmax	**0.0001629**	**0.0008485**	0	**0.001573**	**1.71E-06**	**4.52E-07**
P RHmax	1	1	**0.02359**	0	**1.68E-08**	**0.006549**
G1 RHmax	**1.40E-09**	**5.35E-09**	**2.56E-05**	**2.52E-07**	0	**5.78E-12**
Amb RHmax	1	1	**6.78E-06**	0.09824	**8.67E-11**	0

Regarding RHmin, C1's curve is nearly superimposed to the AMB curve until mid autumn of 2016. Since then, higher RHmin values were obtained (Fig. 5b). C2 showed a similar fluctuating curve as AMB but with higher RHmin values during most of the recorded interval (Fig. 5c). P showed an almost superimposed curve to AMB (Fig. 5e). The Kruskal-Wallis test indicates that C1 and P were not significantly different from the record obtained for the AMB. On the contrary, C2 values significantly differed from the AMB measurements (Table 4).

Table 4. Kruskal – Wallis test for minimum relative humidity (RHmin) values H (Chi^2) = 134.7; Hc (tie corrected) = 135; p_{same} = 2.107E-27. Mann-Whitney pairwise comparisons, Bonferroni corrected (below diagonal) \ uncorrected (above diagonal). Bold numbers indicate statistically significant differences at a p-value of 0.05.

Test de Kruskal - Wallis pour les valeurs minimales d'humidité relative (RHmin) H (Chi^2) = 134.7; Hc (corrigé) = 135; p_{same} = 2.107E-27. Comparaisons par paires de Mann-Whitney, Bonferroni corrigé (en dessous de la diagonale) \ non corrigé (au- dessus de la diagonale). Les chiffres en gras indiquent des différences statistiquement significatives à une valeur de p de 0.05.

	C1 RHmin	C2 RHmin	C3 RHmin	P RHmin	G1 RHmin	Amb RHmin
C1 RHmin	0	**9.60E-05**	**1.23E-12**	0.6501	0.293	**0.00509**
C2 RHmin	**0.00144**	0	**0.02183**	**3.62E-06**	**0.0002959**	**9.64E-10**
C3 RHmin	**1.84E-11**	0.3275	0	**1.11E-19**	**4.07E-16**	**1.84E-20**
P RHmin	1	**5.44E-05**	**1.67E-18**	0	0.1076	**0.02066**
G1 RHmin	1	**0.004439**	**6.10E-15**	1	0	**6.62E-05**
Amb RHmin	0.07635	**1.45E-08**	**2.76E-19**	0.3098	**0.0009927**	0

The RH curves of the enclosures C3 and G1 (Fig. 5d,f) were very different from the described above. C3 values both of RHmax and RHmin showed very little fluctuation, and also the amplitude between both was usually less than 5% (Fig. 5d). In this microenvironment, fossils remained at a RH mean value close to 60%. The RH curves obtained in G1 (Fig. 5f) showed higher fluctuations than in C3 but were much more attenuated than the AMB record. RHmax and RHmin fluctuations were usually coupled and the difference between both was usually less than 10%. Despite the differences described in the RH curves of C3 and G1, both enclosures significantly departed from the RH values of the AMB (Tables 3,4). Regarding the mean values of RH in these enclosures, for C3 was around 60% and for G1 about 54%.

Relative humidity box-plots of mean and standard deviation were useful to evaluate the dispersion of the measurements during each season (Fig. 6). AMB box-plots distribution show a sinusoidal pattern of variation with a significant dispersion of RH values that cannot be linked to a particular season of the year (Fig. 6a). For example, autumn 2015 values showed smaller whiskers than autumn 2016 values; winter 2015 showed higher dispersion than winter 2016, and summer 2016 - 2017 showed higher RH dispersion than the previous year. C1 box-plots had a similar sinusoidal pattern as the AMB but with slightly lower dispersion of values, except during spring and summer 2016 - 2017 (Fig. 6b). C2 and P box-plots showed in general less dispersion than the AMB (Fig. 6c,e), and this is especially significant for C2 from winter 2016 to summer 2016 - 2017. C3 and G1 box-plots displayed significantly less dispersion of mean values and standard deviation (Fig. 6d,f) compared to the AMB. Moreover, the values were more stable during the four seasons. Despite some outliers, C3 showed the lowest standard deviations.

[Fig. 6 near here]

Frequencies of maximum RH values show that C1, C2 and P had a similar distribution as the AMB conditions with slight differences (Fig. 7a). The more frequent range of RH in the AMB was 71% - 80%; in C1 and P this was 61% - 70%, and C2 showed an equal frequency for these two ranges. In a similar frequency to the AMB (around 15%), C1 recorded RHmax in the range 81% - 90%. C3 and G recorded different frequencies. C3 only recorded RHmax in the ranges 51% - 60% and 61% - 70% with similar frequencies each. G1 recorded the highest frequency of all containers in the 51% - 60% range (during half of the time interval considered), followed by less than 30% of the time in the 61% - 70% range. This enclosure also recorded the highest frequency (around 20%) in the 41% - 50% range of RHmax.

[Fig. 7 near here]

Regarding the minimum values of RH, all enclosures except C3 recorded similar frequencies (Fig. 7b). The most frequent range of RHmin was 41% - 50% with the exception of C2 in the range 51% - 60%. Of these, G1 showed the smallest variation as frequencies almost varied equally in both preceding ranges while C2 recorded the highest variations with values in all ranges considered. C3 was the more stable microenvironment as the range 51% - 60% predominated more than 90% of the time span considered.

4. Discussion

The variation of the environmental parameters in the Palaeontological Collection at Facultad de Ciencias, Montevideo, Uruguay can be explained by multiple factors. The more general is the temperate, humid local climate with seasonally fluctuating temperatures. To these general trends, variations derived from large-scale phenomena such as ENSO (El Niño Southern Oscillation) may modify some environmental parameters, such as temperature and rainfall. During the years considered in the present study, near Montevideo the mean maximum temperature was between 21.5 °C and 23 °C and the mean minimum temperature recorded varied between 11 °C and 12 °C. The mean maximum relative humidity varied between 88% and 90%, and the minimum relative humidity recorded was between 45% and 51% according to data from the Instituto Nacional de Investigación Agropecuaria (INIA, 2020). The variation observed in Tmax and Tmin during the two years considered in this analysis can be attributed to the general seasonal cyclicity in temperature. At a smaller scale regarding the building envelope, the physical location of the collection in a room towards the exterior and not at the building's core determines an increased influence by the outside environmental conditions (e.g., Hilberry, 1995; Sebor, 1995). This situation is of special concern due to the effect of a large exterior window in the climate control of the storage area, and the lack of a HVAC (Heating Ventilating Air Conditioning) system. Other factors that probably influenced the environmental measurements in a shorter term were those related to the collection room and cabinet conditions, such as the use of the collection area for many different activities, such as sample storage, fossil preparation or restoration and even inquiries of specimens, and in situ data recording (see Rojas, 2011). All of these variables rendered more adequate a cabinet-based microclimate control approach.

The environmental variability found was assessed in most of the storage units considered but attenuated in different degrees. Measurement curves, Kruskal-Wallis tests and frequencies analyses showed that Tmax and Tmin values behaved differently. Meanwhile Tmin showed homogeneity among the enclosures and the ambient, Tmax varied depending on the enclosure, although the data suggests that fossil specimens were exposed to lower than ambient Tmax while being isolated at some degree. The difference between the Tmax recorded in the ambient and some of the enclosures reached 4ºC, with fossils experiencing the less extreme temperatures inside storage cabinets. The cardboard box (C2) and the lidded plastic box (C3) were the microenvironments with lower Tmax compared to the ambient. Other analyses applied, such as the box-plots also suggested a buffering effect from ambient temperature record. The seasonal distribution of box-plots was not equal for each seasonal set of values, as

for example in the winter of 2016 a higher dispersion of values was recorded, being winter the less comparable paired season.

All of the enclosures showed a lower dispersion of values than the ambient, thus supporting the buffering effect of different kinds of isolation from the room environment. It is significant that the peaks or the highest temperatures were not reached inside any of the storage units, and that the fluctuations were also attenuated. This suggests better conditions inside microenvironments for the conservation of the fossils in our collection, which is in agreement with the findings by Szczepanowska et al. (2013) for an entomological collection.

Unlike temperature, relative humidity in the ambient did not show a clear seasonal pattern, varying in an unpredictable way. This is certainly a factor of concern as the rate of fluctuation of environmental parameters affects the adequate conservation of collections (Ashley-Smith, 1999). The results showed that overall, the enclosures C1, C2 and P, tended to keep slightly lower RHmax and higher RHmin values than the ambient, despite some measurements did not significantly differ as depicted by the variance test. Thus, C1, C2 and P provide although little, some protection for RH fluctuations in our collection room.

The measurements of RH obtained in C3 and G1 showed significantly less fluctuation than the ambient values. Thus, both the lidded plastic boxes and the tightly closing cabinet were effective in buffering the RH fluctuations verified for the room environment. In addition, the 60% RH mean value with <5% amplitude between RHmax and RHmin in C3, and the 54% RH mean value with <10% amplitude between RHmax and RHmin in G1 can be considered adequate for most kinds of collections (National Museums Director's Conference, 2009; Bickersteth, 2016; Michalski, 2016).

Despite it would be desirable to ensure a stable environment for the whole collection area instead of generating multiple stable microclimates (Larkin et al., 1998), this is not achievable in our collection because of its current physical location and use regime. Instead, in view of the obtained results, actions are being taken at a smaller scale in order to improve and enhance the long term preservation of the fossil specimens. Similar results were obtained during a 6 months environmental monitoring of an entomological collection that demonstrated the effectiveness of storage cabinets in protecting from large fluctuations in RH (Szczepanowska et al., 2013).

Specimen containers stored in non-sealed cabinets in the Palaeontological Collection have been progressively substituted from open cardboard boxes and trays to plastic lidded boxes (Rojas, 2011). Fossils that because of their size solely used to rest upon shelves have also been included in plastic containers. Similarly, other palaeontological collections have substituted the traditional open cardboard boxes by plastic lidded cases or bags to overcome the natural deterioration, pest attacks or damaging pollutants affecting cardboard containers (e.g. Montero and Diéguez, 1991; Devincenzi and Azar, 2019). Previous studies showed that several plastics including polypropylene are reasonable moisture barriers (Baker, 1995). In addition, Larkin et al. (1998) compared different plastic box brands and compositions of empty containers (polyethylene vs. polypropylene) as a barrier to fluctuating environmental conditions. They found in a much shorter time span than the present study (weeks or a month), and under more extreme RH fluctuations, that polyethylene containers performed better than polypropylene ones under fast fluctuations regime. However, no large differences were detected by the authors under sustained RH variations. Our results showed that the polypropylene containers did protect the specimens from the ambient RH fluctuations over a two year basis.

Other side benefits of the use of plastic containers are the possibility of stacking (e.g., on high drawers and shelves), the availability of an acceptable range of sizes that cover many of the out-sized fossil vertebrate specimens, and the fact that they nest while being empty allowing for a more efficient space use when stored (Larkin et al., 1998). Moreover, the plastic boxes used in our collection also have a moderate cost. Even though plastic containers may also be sensitive to agents of deterioration (see Blank, 1990; Williams, 2002; Fenn and Williams, 2018), polypropylene boxes show a good resistance to acids, bases, oils, organic solvents, water, high humidity and a fair resistance to sunlight (Baker, 1995). In order to guarantee their effectiveness as barriers for environmental fluctuations, and to make a responsible use of these containers (e.g. Madden et al., 2017), an inspection of the plastic boxes used in the Palaeontological Collection has been periodically carried out. Until now, we have not observed any macroscopic damage in the oldest plastic containers that were incorporated a decade ago.

The isolation provided by the lidded boxes and tightly closing cabinet also protects fossil specimens and labels from other agents of deterioration, such as pests and dust (Weintraub and Wolf, 1995). As noted by Rojas (2011) silverfish (Lepisma saccharina) as well as the evidence of their activity in damaged labels, have been occasionally found in the old collection cabinets. Dust also is deposited on the shelves of the mobile rack of shelves and inside cabinet drawers. However, no dust or pests have been found so far nor inside the tightly sealing cabinets nor in the plastic cases. The transparency of the boxes used also allows the inspection of labels and specimens without the need of opening them, adding to the long term durability of their lids (see Larkin et al., 1998). The present study demonstrated that sealed cabinets and the use of plastic lidded cases in not tightly closing storage furniture are useful for reducing detrimental ambient

environmental fluctuations, therefore contributing to the long term preservation of the fossil specimens. The results here obtained represent a starting point for future specimen-based experimental research approach targeted to evaluate the state of conservation of the fossils in the Palaeontological Collection.

5. Conclusions

The most risky environmental parameter for the conservation of the fossil specimens in the Palaeontological Collection at Facultad de Ciencias is relative humidity as fluctuations are important and unpredictable as reflected in the ambient hygrothermometer.

The isolation of the specimens by means of progressive enclosures has proved useful to minimise the impact of inadequate and fluctuating environmental parameters, especially in RH.

This study suggests that not all fossil containers are equally effective in their environmental buffering capacity. It is safer for specimens to substitute traditional cardboard containers by closed plastic ones. In addition, we found that the more sealed the container or cabinet was, the best isolation for environmental fluctuations it provided.

Disclosure of interest

The authors declare that they have no competing interest.

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Figure captions

Fig. 1. Location of the hygrothermometers in the selected storage units (arrows). (a) Collection area ambient (AMB); (b) Drawer in a non sealed cabinet (P); (c) mobile nontightly sealing modular rack of shelves (C1), and

lidded plastic box inside C1 (C3); (d) cardboard box inside C1 (C2); (e) drawer in a tightly sealing cabinet (G1). Emplacement des hygrothermomètres dans les unités de stockage sélectionnées (flèches). (a) Environnement de la collection (AMB); (b) tiroir dans une armoire non scellée (P); (c) étagère modulaire mobile non étanche (C1), et boîte en plastique avec couvercle à l'intérieur de C1 (C3); (d) boîte en carton à l'intérieur de C1 (C2); (e) tiroir dans une armoire hermétique (G1).

Fig. 2. Temperature linear graphs. (a) Collection area ambient (AMB) maximum temperature values (red / upper line), minimum temperature values (blue / lower line); (b-f) Container (C1, C2, C3, P and G1) maximum temperature values (red / upper line), minimum temperature values (blue / lower line) compared to AMB (grey dashed lines). Graphiques linéaires de température. (a) Valeurs maximales de température ambiante (AMB) de la collection (rouge / ligne supérieure), valeurs minimales de température (bleue / ligne inférieure); (b-f) Conteneur (C1, C2, C3, P et G1) valeurs maximales de température (rouge / ligne supérieure), valeurs minimales de température (bleue / ligne inférieure) par rapport à AMB (lignes grises en pointillés).

Fig. 3. Box-plots of the standard deviation of maximum and minimum temperature values, for each season between 2015 and 2017. (a) Collection area ambient (AMB); (b) mobile non- tightly sealing modular rack of shelves (C1); (c) cardboard box inside C1 (C2); (d) lidded plastic box inside C1 (C3); (e) drawer in a non sealed cabinet (P); (f) drawer in a tightly sealing cabinet (G1).
Diagrammes en boîte de l'écart type des valeurs de température maximale et minimale, pour chaque saison entre 2015 et 2017. (a) Ambiante de la collection (AMB); (b) étagère modulaire mobile d'étagères non étanches (C1); (c) boîte en carton à l'intérieur de C1 (C2); (d) boîte en plastique avec couvercle à l'intérieur de C1 (C3); e) tiroir dans une armoire non scellée (P); (f) tiroir dans une armoire hermétique (G1).

Fig. 4. Frequencies of temperature ranges. (a) Maximum temperature values; (b) Minimum temperature values.
Fréquences des plages de températures. (a) Valeurs maximales de température; (b) valeurs minimales de température.

Fig. 5. Relative humidity linear graphs. (a) Collection area ambient (AMB) maximum humidity values (orange/ upper line), minimum humidity values (green / lower line). (b- f) Containers (C1, C2, C3, P and G1) maximum humidity values (orange/ upper line), minimum humidity values (green / lower line) compared to AMB (grey dashed lines). Graphiques linéaires d'humidité relative. (a) Valeurs d'humidité maximale du ambiante de la collection (AMB) (orange / ligne supérieure), valeurs d'humidité minimale (vert / ligne inférieure). (b-f) Conteneurs (C1, C2, C3, P et G1) valeurs d'humidité maximale (orange / ligne supérieure), valeurs d'humidité minimale (vert / ligne inférieure) par rapport à AMB (lignes grises en pointillés).

Fig. 6. Box-plots of the standard deviation of maximum and minimum relative humidity values for each season between 2015 and 2017. (a) Collection area ambient (AMB); (b) mobile non- tightly sealing modular rack of shelves (C1); (c) Cardboard box inside C1 (C2); (d) Lidded plastic box inside C1 (C3); (e) Drawer in a non-sealed cabinet (P); (f) Drawer in a tightly sealing cabinet (G1).

Diagrammes en boîte de l'écart type des valeurs d'humidité relative maximale et minimale, pour chaque saison entre 2015 et 2017. (a) Ambiante de la collection (AMB); (b) étagère modulaire mobile d'étagères non étanches (C1); (c) boîte en carton à l'intérieur de C1 (C2); (d) boîte en plastique avec couvercle à l'intérieur de C1 (C3); e) tiroir dans une armoire non scellée (P); (f) tiroir dans une armoire hermétique (G1).

Fig. 7. Frequencies of relative humidity ranges. (a) Maximum relative humidity values; (b) Minimum relative humidity values.

Fréquences des plages d'humidité relative. (a) Valeurs maximales d'humidité relative; (b) valeurs minimales d'humidité relative.

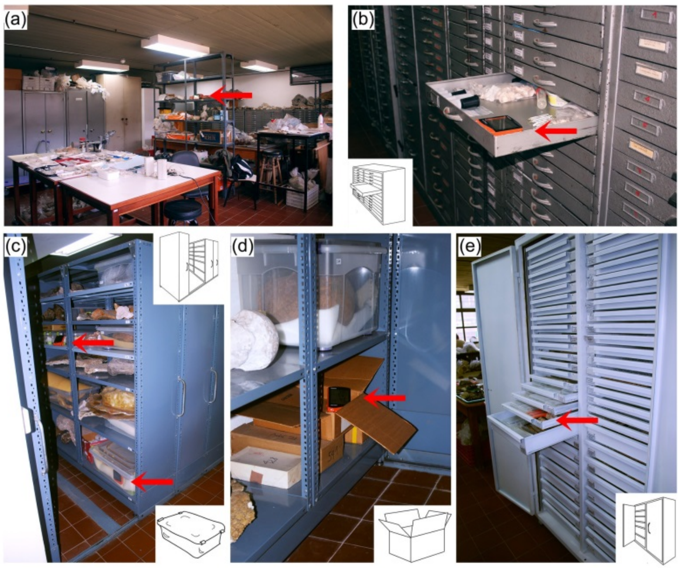

(a)
(b)
(c)
(d)
(e)

Fig. 1

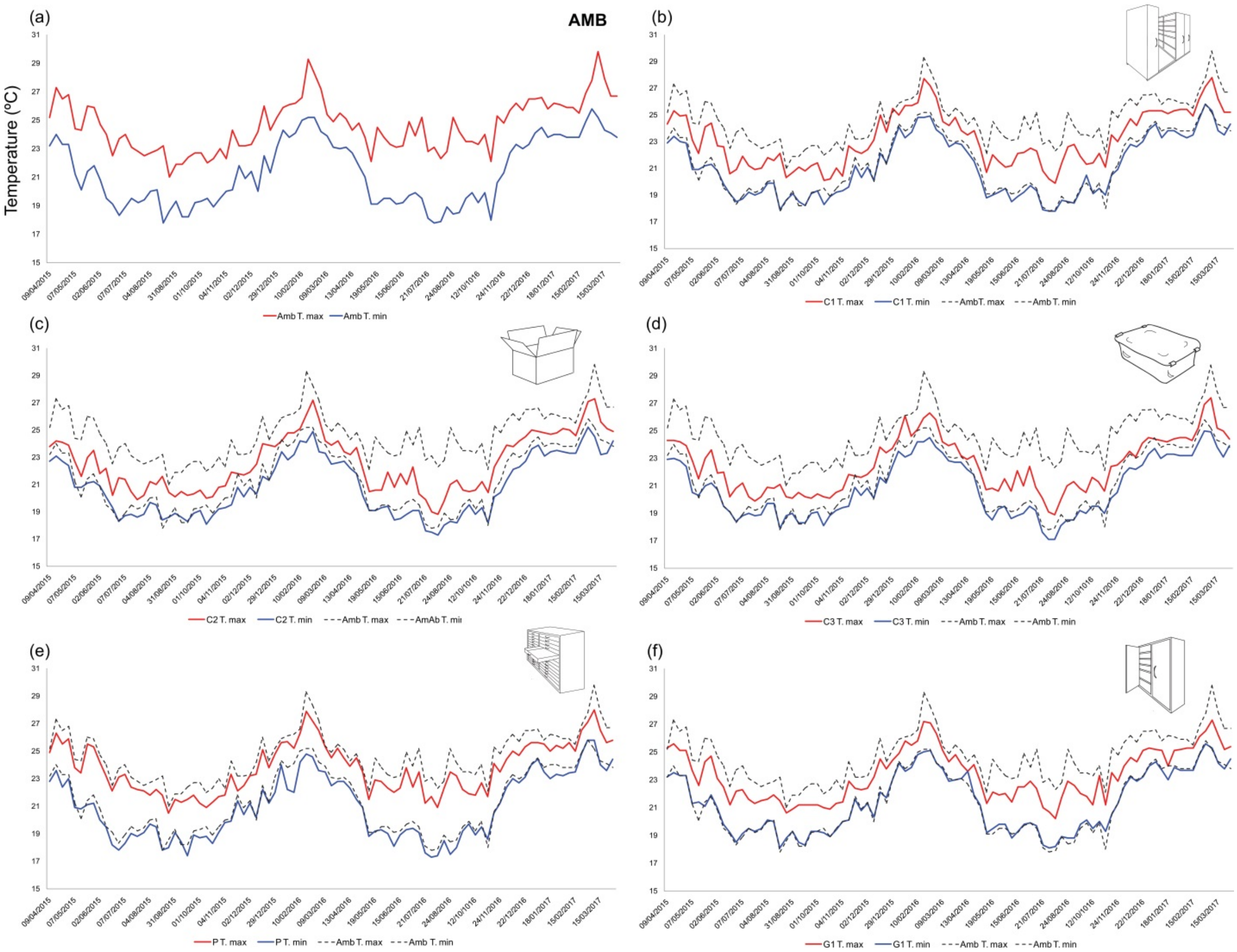
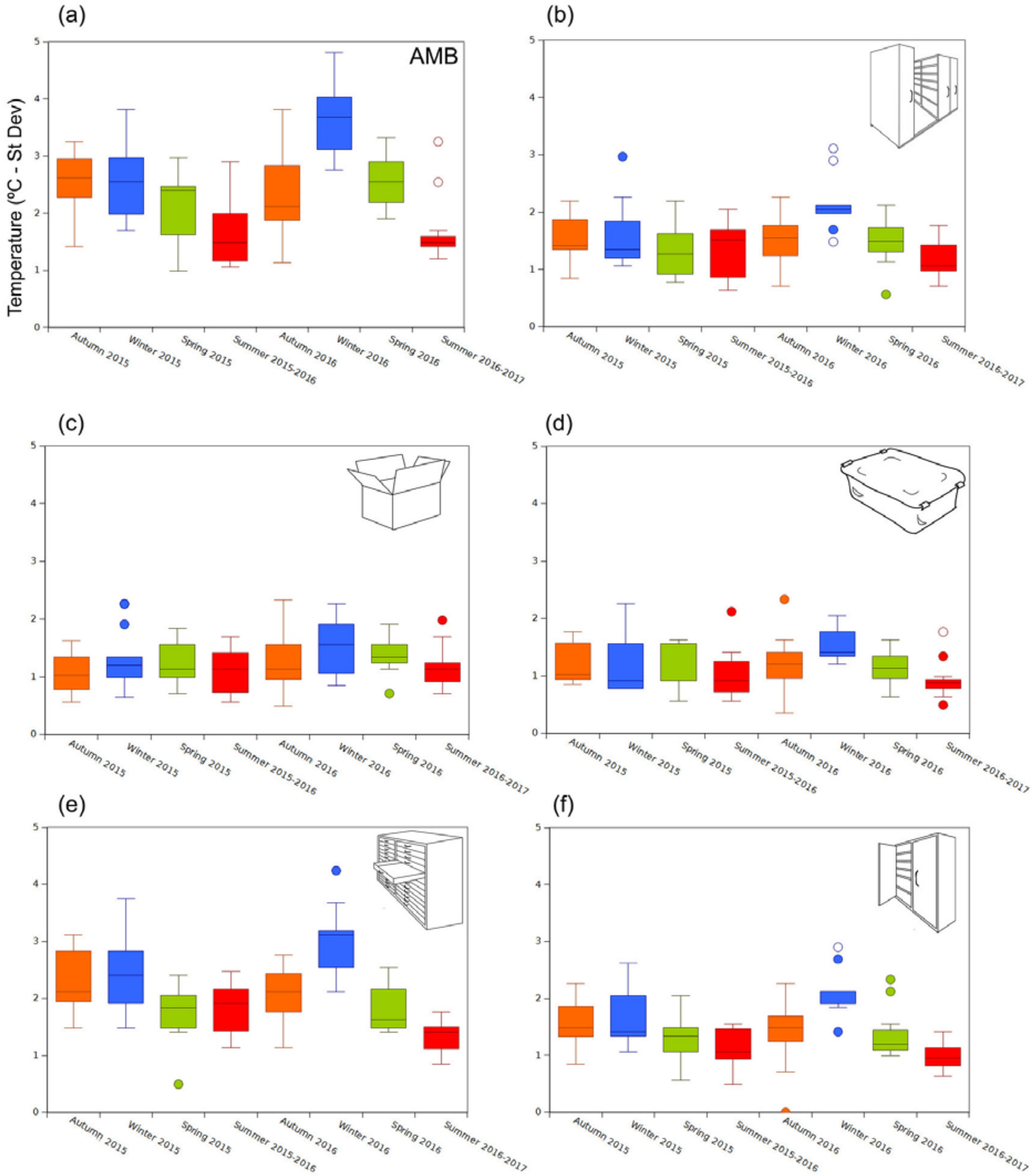

(a)
AMB
Temperature (°C)
Amb T. max
Amb T. min
(b)
C1 T. max
C1 T. min
Amb T. max
Amb T. min
(c)
C2 T. max
C2 T. min
Amb T. max
(d)
C3 T. max
C3 T. min
Amb T. max
Amb T. min
(e)
P T. max
P T. min
Amb T. max
Amb T. min
(f)
G1 T. max
G1 T. min
Amb T. max
Amb T. min

Fig. 2



(a)
AMB
Temperature (ºC - St Dev)
(b)
(c)
(d)
(e)
(f)
Autumn 2015
Winter 2015
Spring 2015
Summer 2015-2016
Autumn 2016
Winter 2016
Spring 2016
Summer 2016-2017

Fig. 3

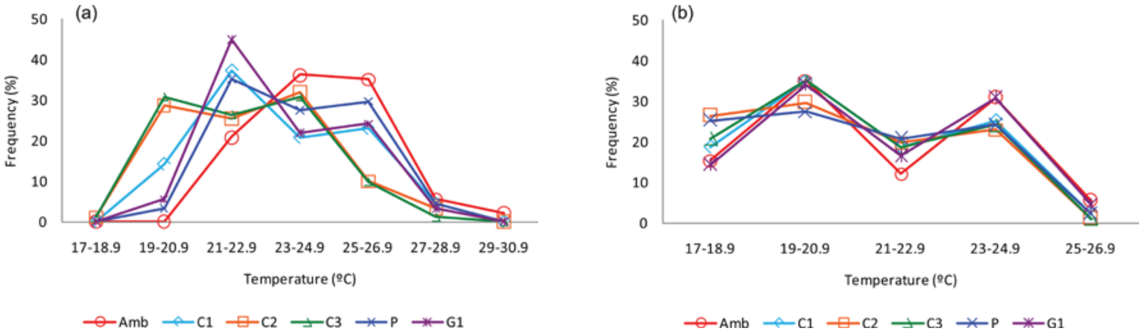

(a)
(b)
Frequency (%)
Temperature (ºC)
17-18.9
19-20.9
21-22.9
23-24.9
25-26.9
27-28.9
29-30.9
Amb
C1
C2
C3
P
G1

Fig. 4

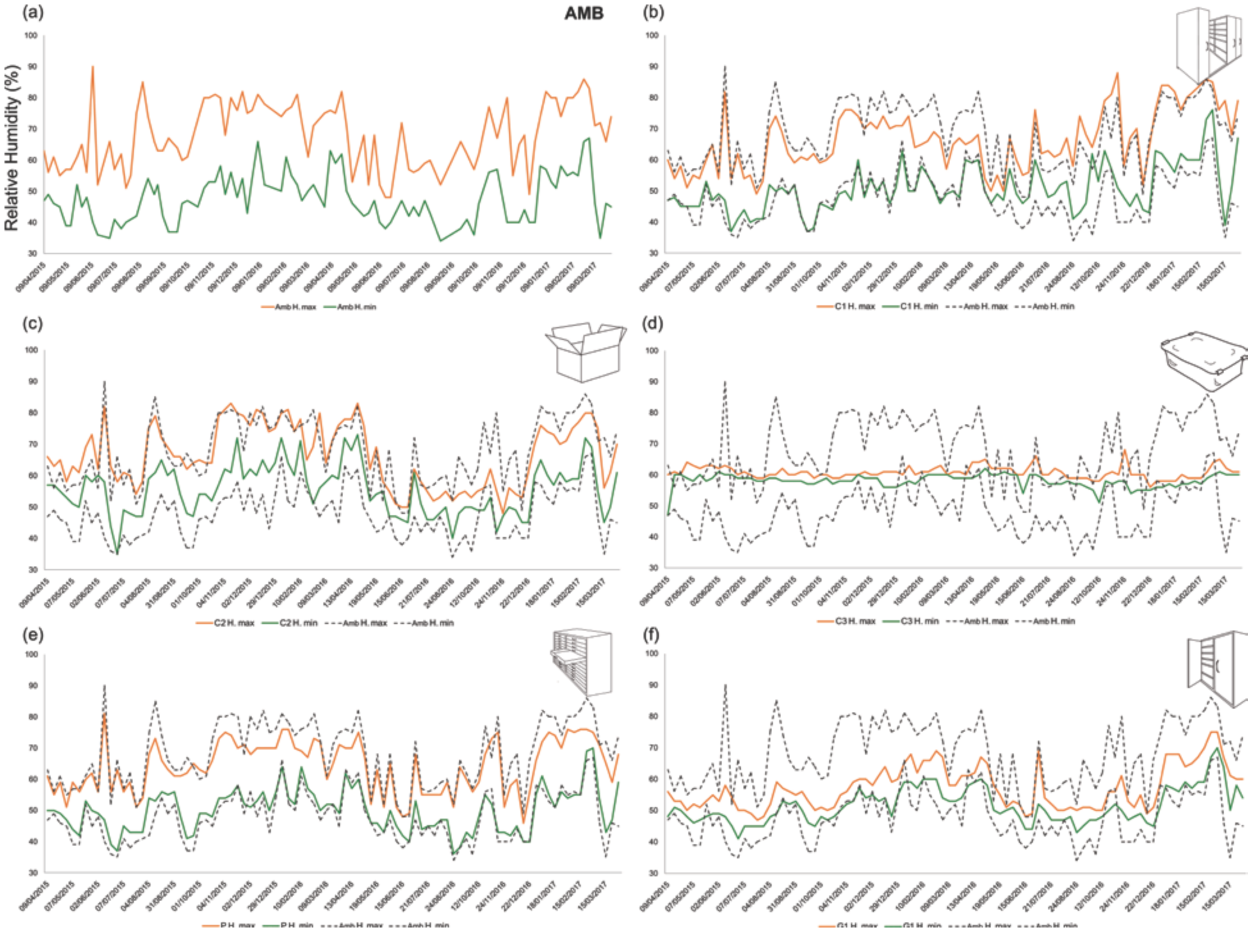

(a)
AMB
(b)
(c)
(d)
(e)
(f)
Relative Humidity (%)

Fig. 5

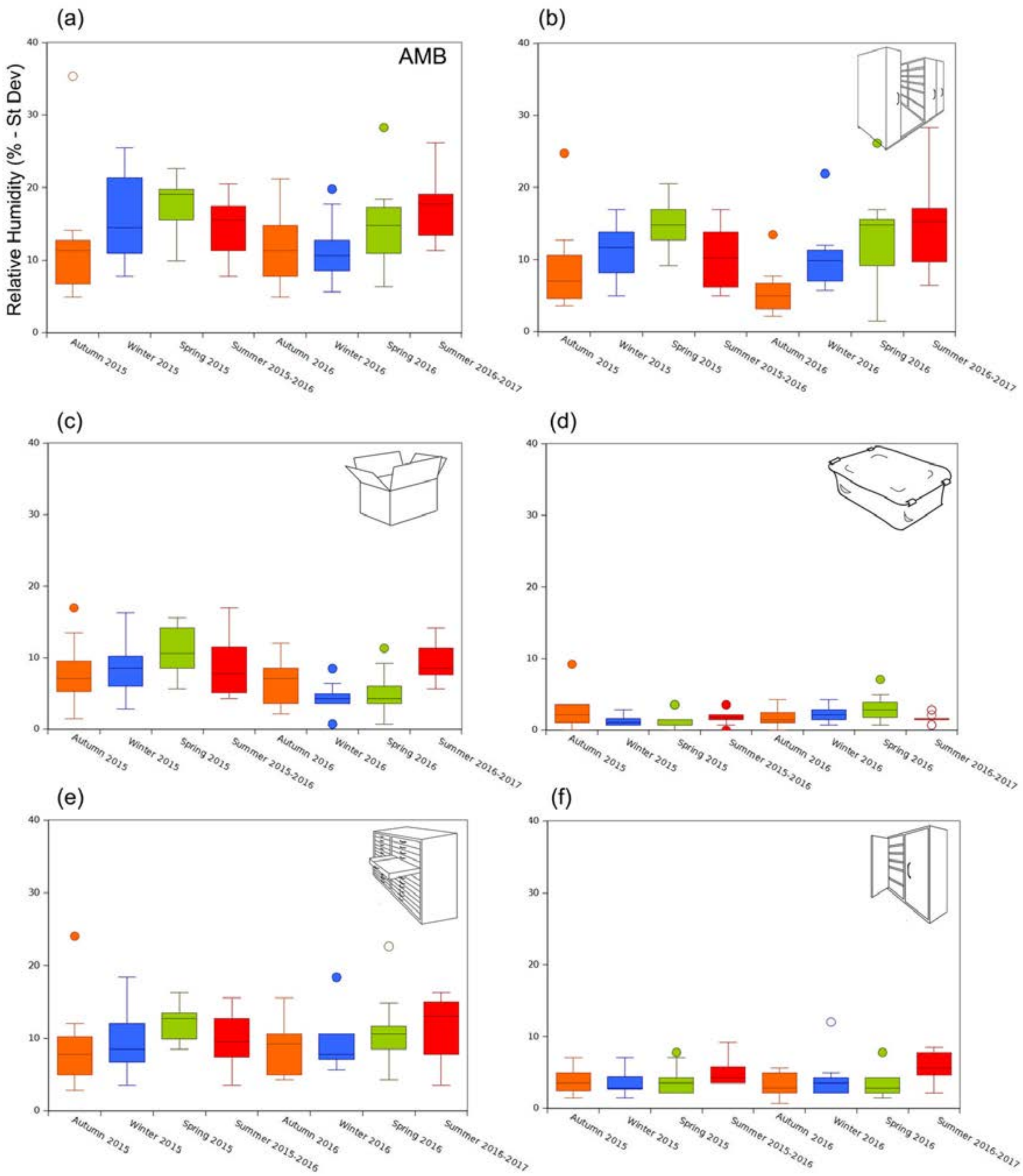

(a)
AMB
Relative Humidity (% - St Dev)
(b)
(c)
(d)
(e)
(f)
Autumn 2015
Winter 2015
Spring 2015
Summer 2015-2016
Autumn 2016
Winter 2016
Spring 2016
Summer 2016-2017

Fig. 6

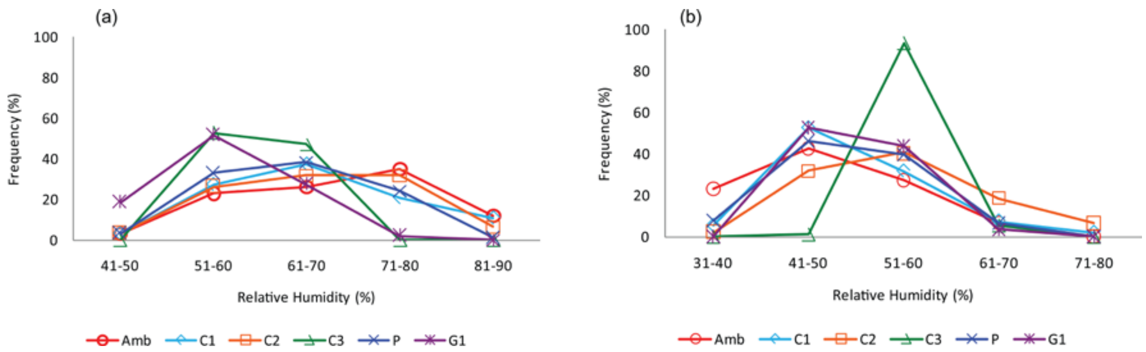

(a)
Frequency (%)
Relative Humidity (%)
41-50
51-60
61-70
71-80
81-90
Amb
C1
C2
C3
P
G1
(b)
Frequency (%)
Relative Humidity (%)
31-40
41-50
51-60
61-70
71-80
Amb
C1
C2
C3
P
G1

Fig. 7