Dansk resumé

I de seneste årtier er der i danske museumsmagasiner opstået skimmelvækst, der udgør en væsentlig udfordring for arbejdsmiljø og kulturarvsbevaring, selvom museer styrer relativ luftfugtighed i intervallet 40-60 % jf. nationale og internationale anbefalinger. Da grænsen for skimmelvækst er estimeret til 75 % relativ luftfugtighed, var væksten uventet og uforklarlig. Årsagen til fænomenet, dets udbredelse, dets indvirkning på arbejdsmiljøet og aktivering af samlingerne i forskning og formidling var ukendt.

Ph.d.-afhandlingen demonstrerer en målrettet indsats for at udrede den uforklarlige skimmelvækst og har til hensigt at udfylde videnshuller i krydsfeltet mellem konserveringsvidenskab, museologi, mykologi og sundhedsvidenskab. Formålet er at karakterisere svampevækst ved lav luftfugtighed med henblik på at vurdere betydningen for museernes virke. Fem studier undersøger fem forskningsspørgsmål. De deltagende museer er Museum ROMU, Nationalmuseet og ni store statsanerkendte museer med national udbredelse. PhD projektets hypotese er testet gennem komplementære analyser, der målretter det tørre indeklima i museumsmagasinerne. Mere end 800 overflade- og luftprøver er analyseret ved hjælp af mikroskopi, dyrkning, morfologisk ID, Big-Dye-Sanger-sekventering, qPCR, Nanopore-CaM og Illumina-ITS ampliqon-sekventering. Arbejdsmiljøet er adresseret ved at måle human svampeeksponering med qPCR og β-N-acetylhexosaminidase, og effekten ved at måle endotoxin og det total inflammatoriske potentiale. Resultaterne er præsenteret i fem forskningsartikler, der hver især bidrager til forståelse af problematikken.

Artikel I finder svampevækst i tre magasiner af arter fra *Aspergillus* sektion *Restricti*, der tolererer lav relativ luftfugtighed. Svampene er detekteret med dyrkning på agar mediet MY50G med lav vandaktivitet efterfulgt af BigDye Sanger-sekventering med brug af CaM-primere, der er egnede til tørketolerante *Aspergillus* arter. Artikel II undersøger svampevækst i Museum ROMU med luftfugtighed ≤ 57%. Dyrkning på agar mediet MY50G, efterfulgt af BigDye Sanger-sekventering af isolater, finder vækst af tørketolerante *Aspergillus* arter, der ikke er identificeret af kommercielle skimmellaboratorier. Artikel III udvider undersøgelsen med ni museer, og Illumina ITS og Nanopore CaM ampliqon sekventering, og detekterer vækst fra syv tørketolerante *Aspergillus*-arter, mens artikel IV finder tørketolerant *Aspergillus* vækst i et husmuseum. Artikel V evaluerer human eksponering for skimmelsvampe i ni magasiner og finder, at museumsarbejde har signifikant effekt på ansattes arbejdsmiljø som følge af eksponering af luftbårne svampe og et højt inflammatorisk potentiale.

Ph.d.-afhandlingen viser, at xerofile *Aspergillus* arter kan vokse i museer, der styrer relativ luftfugtighed i intervallet 40-60 %, men at de kun kan identificeres, hvis analyserne er rettet mod tørt indeklima og xerofile *Aspergillus* arter. Afhandlingen viser også, at skimmelvæksten er landsdækkende, og xeropfile *Aspergillus* arter kan derfor betragtes som en ny kontaminant i danske museer. Afhandlingen viser tillige at arbejde udført i magasiner med svampevækst kan udgøre en helbredsfare for museumsansatte. Afhandlingen understreger behovet for kontinuerligt at genbesøge og modificere anbefalinger for kulturarvsbevaring baseret på ny viden, nye teknologier og skiftende behov i forhold til samlingerne og deres opbevaring. Ph.d.-afhandlingen bidrager også med et betydeligt fremskridt i forhold til den videnskabelige diskussion og teoridannelse inden for forebyggende kulturarvsbevaring, og kan bidrage til at kvalificere en revision af nationale og internationale anbefalinger. Forebyggelse af svampevækst er afgørende for at bevare kulturarv, bibeholde et sundt arbejdsmiljø og sikre museers udadvendte aktiviteter i forskning og formidling.

English summary

In recent decades, fungal growth has occurred in Danish museum repositories, posing a significant challenge to the working environment and cultural heritage preservation. According to national and international recommendations, the museums controlled relative humidity in the 40-60% range. This phenomenon was unexpected and inexplicable since the estimated limit for fungal growth is 75% relative humidity. The cause of fungal growth, its distribution, and its impact on the working environment in relation to the use of museum collections in research and dissemination were unknown.

The PhD thesis aims to unravel the inexplicable fungal growth and fills research gaps in the intersection between conservation science, museology, mycology and health sciences. The aim is to characterise fungal growth at low humidity to assess the impact on museums. Five studies examined five research questions. The examined museums were Museum ROMU, the National Museum of Denmark and nine large state-recognized museums with national distribution. The hypothesis of the PhD project was tested through complementary analyses targeting the dry indoor environment in the museum repositories. More than 800 surface and air samples were analysed using microscopy, cultivation, morphological ID, Big-Dye-Sanger sequencing, qPCR, Nanopore-CaM, and Illumina-ITS amplicon sequencing. The working environment was addressed by measuring fungal exposure with qPCR and β-N-acetylhexosaminidase and the effect of human fungal exposure by measuring endotoxin and the total inflammatory potential. The results were presented in five research articles, each contributing to understanding the problem.

Paper I found fungal growth in three museum repositories from species from the *Aspergillus* section *Restricti* tolerating low relative humidity. The fungi were detected with cultivation on the agar medium MY50G with low water activity, followed by BigDye Sanger sequencing using CaM primers suitable for xerophilic *Aspergillus* species. Paper II examined fungal growth in Museum ROMU, controlling relative humidity ≤ 57%. Cultivation on the agar media MY50G followed by BigDye Sanger sequencing of isolates found growth of xerophilic *Aspergillus* species that commercial industrial hygiene laboratories did not identify. Paper III expanded the study to nine museums and included the molecular techniques Illumina ITS and Nanopore CaM amplicon sequencing to detect seven xerophilic *Aspergillus* species. Paper IV found xerophilic *Aspergillus* growth in a house museum. Paper V evaluated human fungal exposure in nine museum repositories and found that three typical museum work tasks significantly affected employees' working environment due to exposure to airborne fungi and high inflammatory potential.

The PhD thesis shows that xerophilic *Aspergillus* species can grow in museums that maintain relative humidity in the 40-60% range but can only be identified if the analyses are aimed at dry indoor environments and xerophilic *Aspergillus* species. The thesis also shows that mould growth is nationwide, and xerophilic *Aspergillus* species are proposed as a new contaminant in museums. The thesis also shows that work tasks in fungal-colonised museum repositories can pose a health risk for museum employees. The thesis emphasises the need to continuously revisit and modify recommendations for cultural heritage preservation based on new knowledge, new technologies, and changing needs about the collections. The PhD thesis contributes significantly to the scientific discussion and theory formation in preventive conservation and may contribute to qualifying a revision of national and international recommendations for heritage preservation. Prevention of fungal growth is crucial for preserving cultural heritage, maintaining a healthy working environment and ensuring museums' outward-looking activities in research and dissemination.