FACTORS INFLUENCING THE DETERIORATION OF HISTORIC STRUCTURES AT DECEPTION ISLAND, ANTARCTICA

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Resumen

La Isla Decepción, parte de las Islas Shetland del Sur en la Antartida, tiene una larga historia de actividad humana. Dicha isla corresponde a un volcán activo y es uno de los sitios donde las embarcaciones pueden ingresar debido a la presencia de una caldera inundada con agua de mar. Aprovechando este accidente geográfico, una estación ballenera fue establecida en la isla en 1906, la cual estuvo operativa hasta 1931. El Estudio Británico en la Antártica (British Antarctic Survey) comenzó a operar desde una base usando parte de la estación ballenera en 1944, y Chile estableció una base en la ensenada Péndulo en 1955 donde se realizaron estudios científicos. Las actividades volcánicas ocurridas en 1967 y 1969 destruyeron la base Chilena y parte de la estación ballenera, las cuales fueron abandonadas. Las estructuras y artefactos remanentes de dichas actividades son considerados Sitios y Monumentos Históricos protegidos (No. 71 & 76). Determinaciones del grado de descomposición de dichas estructuras revelan que está ocurriendo un importante deterioro, y que el mismo se encuentra en un grado de avance mucho mayor que el observado en otros sitios históricos de la Antartida. Curiosamente, además de la podredumbre blanda frecuentemente encontrada en maderas históricas de la Antartida, se encontró la presencia de hongos causales de podredumbre blanca y marrón de la madera. Estos hongos son típicamente encontrados en ecosistemas templados y su presencia en maderas de la Antartida no ha sido previamente descrita. Numerosos factores contribuyen a la creciente tasa y expansión de la descomposición que ocurre actualmente en la Isla Decepción. Estos incluyen a una diversa y agresiva combinación de hongos descomponedores de madera, actividad volcánica que ha cubierto a la madera con lava y suelo, condiciones ambientales favorables para la actividad de los hongos descomponedores, junto con una gran cantidad de madera llevada hacia la Antartida por más de un siglo. El mejor entendimiento de los mecanismos de deterioro que amenazan la permanencia de las estructuras y artefactos en la Antartida es el primer paso para decidir medidas de manejo conservacionista de estos importantes sitios históricos. La información generada en este estudio puede ser utilizada para diseñar un plan de manejo que limite la descomposición y preserve las maderas históricas en el largo plazo.

Introduction

Deception Island, part of the South Shetland Islands in Antarctica, has a long history of human activity. It is an active volcano and is one of the rare locations where ships may enter a sunken caldera flooded with seawater (Figure 1). This unique geologic feature has provided protection to mariners, which lead to the first human visitation to the island by sealers in the early 1800s. The island later became the site of a whaling station in 1906 (Figure 2). In 1931, whaling operations ceased and in 1944 the British Navy established a wartime base called “Base B” at the site of the whaling station. After WWII, the Falkland Island Dependency Survey (FIDS) operated from the site for many years, followed by occupation by the British Antarctic Survey (BAS). A volcanic eruption in 1969 forced the site to be abandoned. Many structures and remnants from the whaling station and various bases are still present today and are deteriorating.

Three structures: the whalers’ barracks, dispensary/store and the magistrate’s residence, were built in Whalers Bay by the Norwegian whaling company operating there for use as part of the land-based whaling station. These were prefabricated wooden structures some of which were also used by the British Antarctic Survey in later years. Pine (*Pinus* spp.) and spruce (*Picea* spp.) were the main types of wood used to construct the buildings. Many other artifacts, such as wooden boats, oak barrel remnants and processing equipment remain at the site from the whaling period. The British later added a generator house to the whalers’ barracks and renamed it “Biscoe House”, built another structure called the “Hunting Lodge” (1955) and also a hangar for the Havilland DHC-3 Otter that was used for conducting survey work. The historical significance of the site was recognized by the international community and the site is now designated under the Antarctic Treaty System as Historic Site and Monument No. 71.

Figure 1. Whalers Bay inside the caldera of Deception Island where structures of the historic whaling station are located along the shore. Photo: Benjamin Held

Figure 2. Structures at the whaling station at Whalers Bay are deteriorating. In addition to historic structures, there are a number of other wooden artifacts and equipment from the whaling period as well as from activities by the British Antarctic Survey located on the island that are also decaying rapidly. Photo: Benjamin Held

The Chilean base, Pedro Aguirre Cerda Station, at Pendulum Cove was established in 1955 where meteorological and volcanological studies were carried out. It consisted of several structures that were used until volcanic eruptions produced lahars (mudflow of pyroclastic material and water) in 1967 and 1969 which demolished the base and forced abandonment. The remains of the station at the site consist primarily of foundation material made of wood and metal. It is now listed as Historic Site and Monument No.76.

Previous research on wooden structures and artifacts in Antarctica has shown that significant deterioration takes place over time and resilient microbes function in this extreme environment albeit at a slow rate (Arenz and Blanchette 2009, Blanchette et al. 2004, Held et al. 2006). Wood decay is occurring at the historic huts located on Ross Island where wood is in contact with the ground. Extensive fungal growth has also occurred inside the historic structures where deterioration of wood and other cultural properties has taken place (Held et al. 2005). The wooden materials at the Deception Island site are situated in a unique and hostile environment and are also being significantly affected by a diverse and aggressive assemblage of wood decay fungi. This, coupled with the volcanic activity on the island, has had a profound influence on the deterioration of the structures and artifacts. Comparisons made with results from investigations of decay occurring at other polar locations indicate that the historical structures and artifacts at Deception Island are being affected by a larger number of more diverse microorganisms causing different forms of degradation and a more rapid rate of wood decay is taking place. This paper provides new information about the factors influencing deterioration of this important historic polar heritage site.

Condition of historic woods at Deception Island

The wooden buildings and artifacts at Whalers Bay and wood remnants at Pendulum Cove have deteriorated extensively. In most areas where wood is in contact with the ground, significant decay has resulted. The decay commonly extends up from the soil to about a meter in the standing structures (Figure 3). Sufficient moisture and the presence of aggressive decay fungi have resulted in extensive damage. One structure exhibiting significant decay is the north side of the whalers' barracks (Biscoe House). This location has advanced stages of decay that have resulted in large holes formed in several areas of the wall (Figure 3). Many other parts of this structure are also affected and the damage is so severe that the structure is likely to collapse in the near future. A significant amount of mud has also entered the north side of the structure and filled many areas. Much of the wood in contact with the soil is being affected by decay fungi.

Figure 3. Left: The north side of Biscoe House showing advanced decay of the wall boards. Right: Decay is occurring in many areas well above the soil line, as shown in these wall boards of the dispensary structure. Photos: Benjamin Held

The dispensary/store was partially destroyed and buried by a lahar resulting from the volcanic eruption in 1969. Sections of the structure have collapsed and others are also precariously close to collapse. Mud has also filled in and around the structure which has led to significant decay of wood in contact with the soil as well as in the wood well above ground level. Support posts in this structure are also severely decayed.

The Magistrate's residence and the Hunting Lodge, a prefabricated hut built by the British in 1955, are structures at the site that are in comparatively better condition than the others. This is in part because the buildings are on foundations that are above the soil (Figure 4). Without contact of the wood to the soil, decay is limited by reduced moisture and less contact with nutrients and soil microbes. Neither of these structures suffered from major damage from the lahar. However, the ground on the northwest corner of the hunting lodge

Figure 4. The Magistrate's residence has a solid foundation that has aided in avoiding deterioration by keeping the structure well above the soil. However, the roof has blown off exposing the interior to moisture. Photo: Benjamin Held

Figure 5. Left: One of several large areas where remnants of barrels are located along the shore at Whalers Bay. Along with other wooden structures and artifacts, these areas serve as an enormous nutrient source for decay fungi. Right: One of several water boats that remain on the beach area that is partially buried and showing advanced deterioration. Photos: Benjamin Held

has been cut away by soil erosion and that part of the building is in danger of collapse. The roof of the Magistrate's residence has blown off and is lying nearby. The inside of this building is now exposed to the elements.

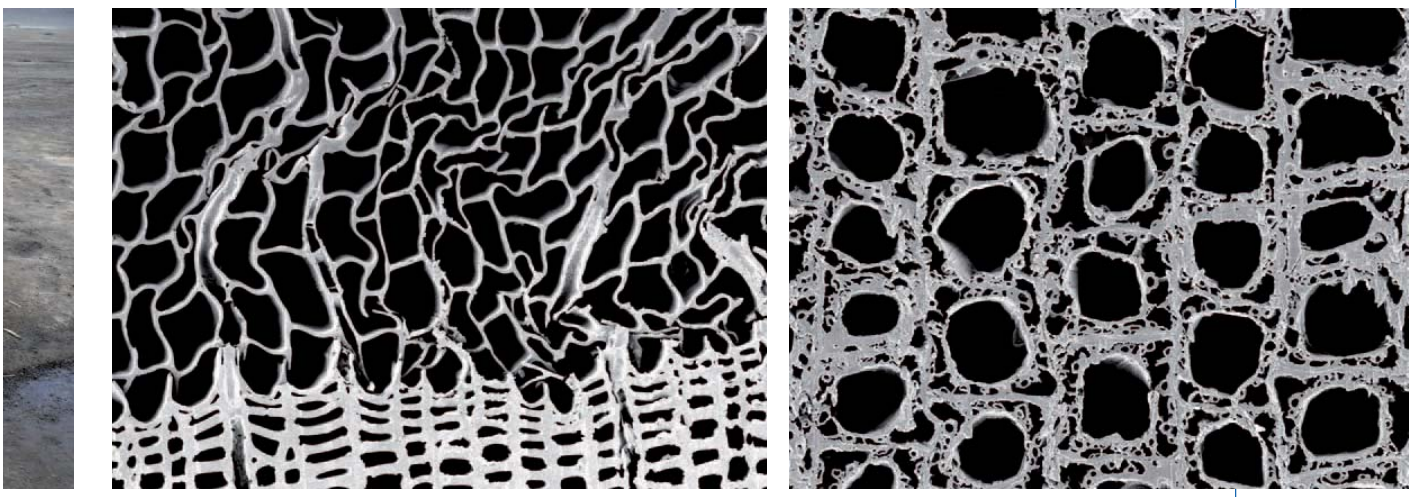
In a southeasterly direction from the buildings along the beach a number of different wooden artifacts can be found (Figure 5). Many of them are half buried in the soil. Most notable are a number of small boats (used by whalers for transporting freshwater to whale processing ships) and wooden barrel depots. The boats are located in a wide area along the beach and are half buried in soil. The boats are extensively decayed not only in areas that are below ground but also in areas well above the soil. There are also several large areas with remnants of oak barrels and this wood is also decaying.

The Chilean station at Pendulum Cove was completely destroyed by lahars in 1967 and 1969 and only a foundation of metal and wood structural elements remain. The wooden remains at this site have decay that is similar to the wood degradation taking place at Whalers Bay with significant decay in wood at ground contact and wood that has been buried.

Decay and fungi present

Scanning electron microscopy was used to examine samples obtained from the site and ascertain what forms of degradation were present. The results show that several types of decay are occurring in affected woods, with many samples displaying an extensive soft rot type of attack and others a brown rot form of wood degradation (Figure 6). Soft rot fungi are known to function in very harsh environments which exclude other types of decay fungi (Blanchette 2003). Brown rot fungi degrade wood differently from soft-rotters and are well known to cause severe strength loss early in the decay process. Brown rot fungi cause a rapid depolymerization of wood constituents primarily targeting cellulose which causes the rapid loss of strength (Eriksson et al. 1990, Zabel and Morrell, 1992). Brown rot decay fungi commonly affect wooden structures in temperate climates and are very important in forest ecosystems as decomposers of organic material. However, it is not common in polar environments, but at Deception Island many of the woods inspected had advanced stages of brown rot. A third type of wood decay found was a white rot affecting buried wood from the destroyed Chilean station at Pendulum Cove. Extensive mycelial cords formed white rhizomorphs on the wood. White rot fungi can degrade all cell wall components and some cause a preferential attack on lignin. The white rot found at Deception Island appears to cause a selective attack on the wood resulting in a bleached appearance and a white-pocket rot form of decay. Generally, strength loss is not significant until advanced stages of decay are reached. No previous evidence of brown or white rot fungi has been reported from other historic wooden structures in Antarctica and both forms of decay by these basidiomycetes on Deception Island are an unusual occurrence in a polar environment.

Determination of the species of fungi attacking the wood was made by isolating from samples and sequencing rDNA from pure cultures. Small wood sections were aseptically placed on various culturing growth media. Fungi that grew out from these sections were transferred and pure cultures obtained. Identification of the cultures was done by extracting rDNA and sequencing the ITS (internal transcribed spacer) region using previously described techniques (Arenz 2009, Gardes and Bruns 1993). Fungi that were isolated that are known to cause a soft rot in wood include species of *Cadophora, Lecythophora, Phialocephala* and *Phiolophora*. *Cadophora* is a common fungus isolated and identified from wood in many polar environments



(Arenz and Blanchette 2009, Arenz et al. 2006, Blanchette et al. 2010, Held et al. 2006). Phylogenetic analysis of *Cadophora* isolates cultured from wood at Deception Island revealed that a very diverse species population (data not shown) was present. The most prevalent brown rot fungus obtained does not match other sequences in GenBank and cultural characteristics suggest this may be a previously unreported species. The white rot fungus is related to other *Pholiota* species and also appears to represent an undescribed species.

Figure 6. Scanning electron micrographs of transverse sections of wood from the whalers' barracks at Whalers Bay affected by fungal decay. Left: Brown rot in spruce wood showing the severe degradation and attack on the cell walls resulting in significant reduction in wood strength and loss of structural integrity of the timbers. Right: Soft rot decay showing cavities in the wood cells caused by the fungus. Many cavities occur in the cell walls and as they enlarge the cavities coalesce causing large holes and significant degradation of the wood substrate. Photos: Benjamin Held

Factors influencing decay

As previously mentioned, the extent and severity of wood decay identified in the wooden structures and artifacts at Deception Island are much more extensive than has been found in historic structures located in other Antarctic locations (Arenz et al. 2009, Blanchette et al. 2010, Blanchette et al. 2004, Held et al. 2006). There are several primary factors that are contributing to the rapid and extensive decay taking place at Deception Island including:

1. Diverse population of decay fungi
2. Environmental conditions conducive for decay
3. Volcanic activity that has covered historic woods with soil
4. Large amounts of exotic wood from many different areas brought to the island during the last century

Diverse fungi in Deception Island's unique ecosystem

A unique ecosystem exists on Deception Island. Active volcanoes are rare in Antarctica and only two, Mt. Erebus and Deception Island, have had activity with recent eruptions. Deception island is home to exceptionally rare flora including eighteen species of plants not found elsewhere in the Antarctic (Deception Island Management Package 2005). Our investigations show that microbial diversity is also remarkably diverse and unusual. The research we carried out has identified approximately 71 taxa of fungi including what appear to be many previously undescribed species. In addition, wood decay fungi have been found that cause three major types of wood degradation; white, brown and soft rots. While the damage caused by the white rot fungi does not appear to be widespread among the wooden materials, the fungi causing brown and soft rot are active and very aggressive causing extensive damage to many woods. Past research suggests that soft rot fungi should be the dominate decay organisms at this Antarctic location, but the diversity of decay fungal species, coupled with moderate temperatures and moisture at the site, has lead to significant decomposition in the historic woods (Blanchette et al. 2010, Held et al. 2006). The origin of the many different decay fungi at Deception Island is not clear. A strong case could be made that fungi were introduced on the timbers or were carried to the island on other materials brought by the many inhabitants over the past decades. They could also be brought in on birds or as wind disseminated spores. However, with many isolates found being genetically different from known species there is a strong possibility that some of these fungi are endemic to Antarctica. Whatever the mode of introduction to the island has been, one underlying factor fueling the decay is the abundant carbon source (coming from all the introduced woods) and conducive temperature and moisture conditions available for colonization and continued survival of the fungi and decomposition of the substrates.

Arenz and Blanchette (2009) described fungal diversity and deterioration at 9 different historic sites on the Antarctic Peninsula with wood structures. While these sites have similar environmental conditions to Deception Island, the diversity profile of fungi (including decay fungi) isolated from wood is quite different. In addition, less decay was observed in wood at these other Peninsula sites as compared to Deception Island.

Environmental Conditions

Deception Island has a polar maritime climate with a mean annual temperature of -3°C. Temperature ranges from -28°C to +11°C and an average high temperature during the months from October to April is 1°C. The mean annual precipitation is 560mm. Comparing Deception Island to that of Ross Island where the historic huts of Scott and Shackleton are located shows considerable differences in climatic conditions (Table 1). At Ross Island, the average yearly temperature is -19°C, average high temperature from October to April is -8°C and there is an average yearly precipitation of 190 mm. The maritime conditions of Deception Island favor warmer temperatures and increased precipitation. Since adequate moisture and temperatures above freezing are necessary for fungi to function, the conditions at Deception Island are allowing microbes to be active many more days per year than at Ross Island. In addition, the precipitation that occurs will likely be a heavier wet snow or rain/snow mix at Deception Island. Observations at the site during our assessment showed that a heavy wet snow accumulated on siding of the structures during storms and subsequent melting leaves considerable moisture on the wall boards and other above ground woods (Figure 7). It was apparent that this moisture absorbing into the wood was providing sufficient moisture for fungal growth and is the reason why decay extends up from the soil into the above ground wood structures. In areas where the bases of structures are buried in mud, decay begins and advances from the ground upward into the structure. Once decay occurs, the porosity of wood changes and the wood becomes more absorbent leading to even more water retention. This exacerbates the problem and allows for increased decay.

Table 1. A comparison of climatic data between Deception Island and Ross Island, Antarctica. Deception Island has much higher precipitation and higher temperatures when compared to Ross Island, enabling decay fungi to function for a longer period of time.

	CLIMATIC DATA			
Location	Ave. Yearly Temp.	Ave. High Oct-April (°C)	Months Ave. High Temp >=0°C	Annual Precipitation (mm)
Deception Island	-3	1	5	560
Ross Island	-17	-8	0	190

Figure 7. The north side of the dispensary at the end of a precipitation event showing accumulation of snow sticking to the wall boards. When this snow melts it is sufficient moisture to support fungal growth and decay. Photo: Benjamin Held

Volcanic Activity

Lahars, specific to areas of volcanic activity, can cause dramatic destruction. Lahars occurred with recent eruptions in 1967 and 1969 and damaged structures at Whalers Bay and destroyed the Chilean base buildings at Pendulum Cove. There are clear implications that this phenomenon has contributed to the severe degradation and condition of the structures. There is a two-fold effect from lahars; first is the destructive force behind the flowing mud and water that damages or obliterates objects in its path and second, there is a change of environment that affects degradation processes in wood. The process of partially burying structures and artifacts brings soil, moisture and microbes that inhabit the soil into contact with the wood substrate and creates an environment conducive for decay by microorganisms (Figure 8). This has led to advanced decay in buried wood and also leads to decay occurring in wood above ground where there is sufficient moisture. These damaging effects are also evident on other artifacts like the barrel remnants and wooden boats on the shore. Several boats are nearly buried and are breaking apart due to the loss of structural integrity caused by decay fungi. In contrast, the Magistrate's residence and Hunting Lodge were largely unaffected by the lahars have far less decay occurring. Generally, the wood of these structures is above the soil line and little to no decay is taking place. However, the Magistrate's residence has soil in contact with wood on the north side of the building that has allowed decay to occur in that area.

There are several areas on the island that have heated geothermal soils with abundant and rare bryophyte communities (Lewis Smith 2005). It is possible that these areas are harboring some of the decay fungi that are normally found functioning in more temperate ecosystems (white and brown rot fungi). Since there is abundant plant material and a range of soil temperatures, these fungi (exotic or indigenous) could be thriving in this area and have spread from these sites to the locations with historic wood. In addition, a report of a mushroom fruiting in one of the large bryophyte stands indicates that there is a resident population of basdiomycetes that exist among the live and dead bryophytes (Lewis Smith 2005).

Figure 8. The dispensary/store has been inundated with mud from a lahar. The mud holds moisture and microbes which creates a conducive environment for decay to take place. Photo: Benjamin Held

Abundant Nutrient Source

Wood is an introduced substrate to Deception Island and Antarctica and the amount of wood present at Whalers Bay is substantial. This abundance of wood from many different places around the world brought in over more than a century has allowed populations of wood decay fungi to become established and proliferate. Fungal populations have most likely changed dramatically since the introduction of wood material and human activity on the island. The addition of wood substrate in the volcanic ecosystem of Deception Island adds a tremendous amount of nutrients to an otherwise very nutrient poor environment. Although it is not yet known what fungi are indigenous to Antarctica and which were brought in on the wood or on other materials, these sites constitute some of the most significantly diverse areas in Antarctica for fungi. It is clear that the

decay fungi found are well adapted to the site, capable of degrading wood and are extremely efficient decomposers.

Management Considerations

Many of the wooden resources at Deception Island are so deteriorated that very little can be done to preserve them. Among them, Biscoe House and the dispensary are precipitously close to collapse. Removing soil away from the base of the structures and artifacts where feasible is recommended to help arrest decay by limiting contact with soil moisture. Perhaps the most appropriate procedures are those that focus resources where conservation work could be feasibly carried out. For instance, repairing the roof of the Magistrate's residence would help protect one of the original structures at the site that is still in relatively good condition. Replacing the roof would protect the interior from further damage and the structure could possibly be used to house interpretive material. Also repairing the foundation of the Hunting Lodge that has washed away would greatly improve the structural stability of this building (Figure 9).

Figure 9. The Hunting Lodge has significantly less deterioration than other structures at the site partly due to a high foundation keeping the wood well above the soil. However the left corner shows erosion of the foundation that is in danger of collapse. Photo: Benjamin Held

The use of preservatives on the wood to stop fungal attack is not an option for several reasons. Most of the effective preservatives contain heavy metals or other compounds that can be toxic in the environment and should not be used in Antarctica. Also, some of the fungi causing decay, such as the *Cadophora* species, are tolerant of preservatives (Daniel and Nilsson 1988) and they would not be effectively controlled by them. Conservation standards would also not allow treatments that are not reversible to be used and the long term effect of material treated with preservatives is unclear. Finally, it would be difficult to successfully treat and infiltrate wood at Deception Island under the extreme Antarctic conditions that can occur there. At the present time, the only effective method of control is to reduce moisture. Therefore, wherever possible conservation measures should work to reduce moisture in wood to limit the rate and extent of decay.

The wooden structures and artifacts at Deception Island provide a legacy of rich polar history that warrants preservation efforts by the international community. The factors influencing decay described in this paper indicate why rapid deterioration has taken place over the last few decades. Understanding decay mechanisms threatening the wood resources is the first step to making informed conservation decisions to protect these and other important polar historic sites. The information provided here can be used to provide more precise management plans to limit decay and preserve the historic woods long into the future.

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