

# A Big Blank White Canvas? Mapping and Modelling Human Impact In Antarctica

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**Abstract**—Antarctica is certainly what most people would consider being the world's last great wilderness; largely untouched and undeveloped by humans. Yet it is not inviolate - there are scientific bases, tourist operations, expeditions, airstrips and even roads. Although these impacts are by and large limited in extent, their very presence in an otherwise "blank" landscape can have effects on the wilderness that far outweigh their relatively small physical footprint. The vastness of Antarctica and the relatively small size and sparseness of human infrastructure presents its own set of special conditions which force us to re-think and re-imagine the concepts of wilderness quality mapping in large polar wildernesses. Here our task is perhaps not to map out where wilderness is but, rather, to map out where human activities and impacts are. Antarctica's vast size means that a multi-scale approach is required to develop an adequate understanding of the spatial pattern of wilderness and human activities. The disproportionate impact of the first human impact on the "Blank Canvas" and subsequent fragmentation of the canvas as a result of increasing and scattered impacts need to be taken into account. A conceptual spatial modelling approach is developed and recommendations for future implementation made.

## Introduction

By most definitions – biophysical, legal, sociological or cultural – Antarctica qualifies as one of the largest wildernesses on Earth. Permanent human infrastructure exists on less than 1% of the 14 million square kilometres of the Antarctic continent (Summerson, 2013). Under the 1991 Protocol on Environmental Protection to the Antarctic Treaty, the Antarctic Treaty area - the area south of 60 degrees latitude south, covering one-sixth of the Earth's surface, or

85 million square kilometres – has been designated “as a natural reserve, devoted to peace and science” (Article 2). The legal protection of Antarctica's “wilderness values” is required to “be fundamental considerations in the planning and conduct of all activities in the Antarctic Treaty area” (Article 3(1)). More specifically, Antarctic Specially Protected Areas can be designated to protect areas with “outstanding” wilderness values (Annex V). Activities “shall be planned and conducted so as to avoid degradation of... areas of... wilderness significance” (Article 3(2)(b)(vi)), primarily through the use of Environmental Impact Assessments (EIAs) (Annex I).

Despite the multiple legal commitments and the obvious condition of Antarctica as wilderness, implementation of the legal requirements and pro-active protection of Antarctica's wilderness have been slow to come by (Summerson and Bishop, 2012; Tin and Hemmings, 2011). Antarctica and other polar wildernesses, like Greenland and Svalbard, are unusual cases in the field of environmental management. In most other environments, humans are trying to protect the little land area that is wild and natural within a much larger matrix of that which is built-up, farmed and domesticated. Environmental management tools such as protected areas and EIAs have been developed primarily to address these situations. However, in a polar wilderness where 99% of the land has no permanent human infrastructure how does one identify areas of “outstanding” wilderness values to designate as a protected area? How does one conduct an EIA and assess the impact of the construction of human infrastructure on wilderness when every construction impacts wilderness irreversibly? Protected areas, EIAs and other existing environmental management tools may not be the most appropriate tools for wilderness protection in these places. If wilderness can be defined as areas with the absence of human disturbance (as proposed in New Zealand, 2011, for Antarctica), then the most direct way to protect polar wildernesses where there have been little or no human presence is to avoid human development entirely. Up till now, polar wildernesses have been protected from human development partly because of their remoteness and harsh climates. However, technological advances, climate warming, globalisation, geopolitics and increased demand for resources, have all contributed towards increasing the pressure to expand the human footprint across even these most remote parts of the planet (Tin et al., 2008; Branding Greenland, 2009; Berkman and Vylegzhanin, 2013). Existing environmental management tools, insufficient though they are, may provide some basic protection to these fragile environments. However, if they were to be used effectively in polar wildernesses where built-up areas are scattered within

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the much larger matrix of wilderness then their application needs to be re-thought and re-imagined.

In order for any environmental management tool to be effective in wilderness protection, there must be an *a priori* knowledge of the location of the area to be protected. This paper focuses on this issue of wilderness mapping in Antarctica. We start from the basic working definition that wilderness is where there is an absence of human disturbance (New Zealand, 2011). This definition is simple and overlooks nuances, such as time (e.g., How long do the disturbance and its impacts last for?), nature of disturbance and impacts (e.g., Do visual, audible, chemical or biological disturbances carry the same weight?) or characteristics of the terrain (e.g., Are areas with more biodiversity have more value as wilderness?). Nonetheless, it remains the one definition that has been debated over a long period of time (since the first meeting of the Antarctic Treaty System's Committee for Environmental Protection in 1999) with the participation of the now, 29 governments which are Consultative Parties to the Antarctic Treaty. Its simplicity also allows us to make some first explorations into some basic concepts of wilderness mapping in a "Big Blank White Canvas".

The terminology "wilderness mapping" is used as it is familiar to most mapping practitioners. However, in Antarctica and other polar wildernesses where the vast majority of the area is undeniably wilderness, our task is not to map out where wilderness is but, rather, to map out where human activities and impacts are located. In this paper, we assume only two categories of land: 1) with human activities and impacts, and 2) without human activities and impacts. We do not take into consideration the surface substrate or biodiversity of the land, duration or nature of human activities and their impacts, or whether any human being would likely to be present to experience such impacts. We focus on exploring the issues of the disproportionate impact of the first human impact on to the "Blank Canvas" and subsequent fragmentation of the canvas as a result of increasing and scattered impacts. We begin this paper with an overview of how wilderness has been mapped in Antarctica in the past. We then discuss a number of issues relevant to the special case of wilderness mapping on a "big blank canvas", including size, scale, effects of initial and subsequent impacts and permanent and transitory impacts. We conclude with some suggestions on the way forward.

## Attempts at Mapping Wilderness in Antarctica

While a number of global scale maps of wilderness areas and wilderness quality have been produced, many of these are of little or no use in regard to Antarctica because they either describe all Antarctica as "wilderness" or avoid mapping the continent altogether because of a lack of suitable data. A small number of mapping exercises have been carried out specifically for Antarctica but these remain limited in their scope and their detail.

McCloskey and Spalding (1989) conducted the first global reconnaissance of wilderness by mapping those areas without large scale human impacts. This was based on very simple fixed criteria and used the Jet Navigation and Operational Navigation Charts to identify areas greater than 400,000 ha

with no mapped roads or other human structures. Due to the limited scale of these maps (1:1,000,000 and 1:2,000,000, respectively) the results for Antarctica are very much generalised with 100% being described as wilderness.

Many wilderness mapping projects adopt the wilderness continuum concept (or environmental modification spectrum) as their basic model (Carver and Fritz, 1999). This assumes that wilderness quality is inversely proportional to the degree of human impact. Pristine wilderness is at one end of the continuum (Hendee et al., 1990). At the opposite end of this spectrum is the indoor and totally urbanised environment of the city centre shopping mall or office block where a person is entirely isolated from the natural world. At all stages in between it is possible to identify various environments with varying levels of human modification and naturalness. The continuum concept has been adopted in more recent studies to model the degree of human impact based on such factors as human population density, settlements, roads, etc. such as the work on the Human Footprint and The Last of the Wild by Wildlife Conservation Society (WCS) and the Center for International Earth Science Information Network (CIESIN) (Sanderson et al., 2002), and land cover change, land-use intensity, fragmentation, climate change, atmospheric nitrogen deposition, and infrastructure development as used in the Globio GEO-3 project (Alkemade et al., 2009). However, because these models are dealing with global databases, the level of detail is low, and so generally results in highly generalised outputs. In addition, both the Human Footprint/Last of the Wild and Globio GEO-3 exclude Antarctica because of a paucity of data.

A recent development of the global wilderness map simplifies the mapping procedure by just mapping roadless areas based on Google map data. In the populated countries of the world this is an interesting first step to mapping opportunities for wilderness as lack of roads limits human impact by restricting accessibility. However, the lack of a road network in Antarctica limits the usefulness of this approach.

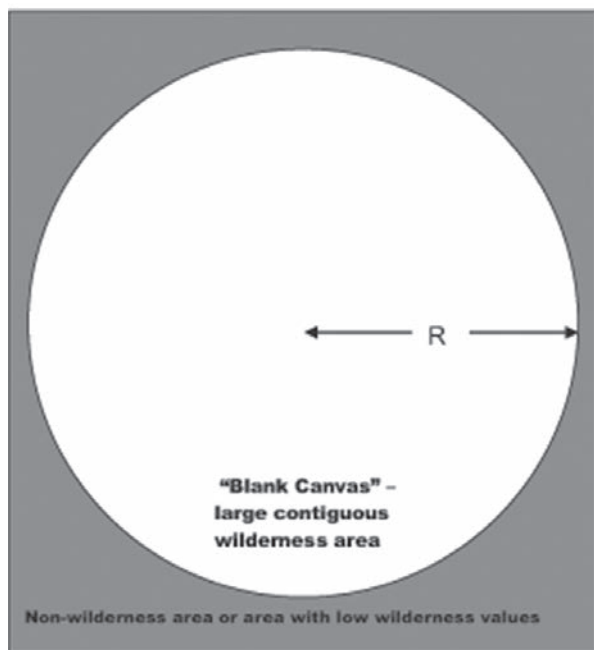
In Antarctica, the only continental-wide maps of the human footprint were developed by Summerson (Tin and Summerson, 2013; Convey et al, 2012). Data on the locations of permanent infrastructure and logistic routes were obtained from the public databases of the Council of Managers of National Antarctic Programs (COMNAP), International Association of Antarctica Tour Operators (IAATO), the Antarctic Treaty Secretariat and subsequent links to websites of National Antarctic Programs for 2011-2012. Once the data were compiled, no further analysis was conducted (such as, addition or scaling) and the locations were plotted on a map of the Antarctic continent. In the process, Tin and Summerson (2011) found that information on major human activity in Antarctica was reasonably well-maintained and relatively centralised, though accessibility was variable. They concluded that compiling data from the different repositories into a common format, building and updating a Geographic Information System (GIS) database of human infrastructure and activity in Antarctica would be a formidable challenge.

On regional to local scales, Hughes et al. (2010) produced maps of human visitation in the Antarctic Peninsula. Based on the reports of field operations of British Antarctic Survey, their results showed a clear expansion of human activity in the region over time. Lynch et al. (2010) mapped the itineraries of tourist cruise ships around the Antarctic Peninsula. Their

results demonstrated the concentration of marine traffic at a few specific locations and the growth in tourism activity over two decades. Using aerial photographs, Klein et al. (2008) have mapped the evolution of the physical footprint of the U.S. McMurdo station over five decades. The station expanded rapidly from 1956 to the 1960s as buildings, fuel tanks and roads were built. Expansion has continued since, albeit at a slower rate.

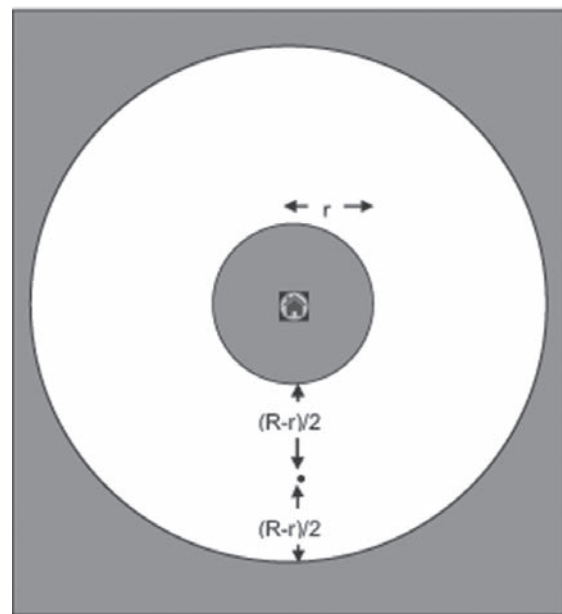
## Tearing Up the Big Blank Canvas

The largely untouched nature of Antarctica creates its own set of challenges for wilderness mapping. Since most of the region is devoid of obvious forms of human impact (global pollution and effects of climate change notwithstanding) any form or level of human development or impact in previously inviolate areas must have an impact that is disproportionate to its size, level or extent when compared to similar developments elsewhere in the world. This “Blank Canvas” model of first human impact is illustrated in Figures 1-3. The first infrastructure constructed on the “Blank Canvas” has the largest relative impact because subsequent developments impact an area that is already impacted. In addition, new developments impact new ground and contribute towards



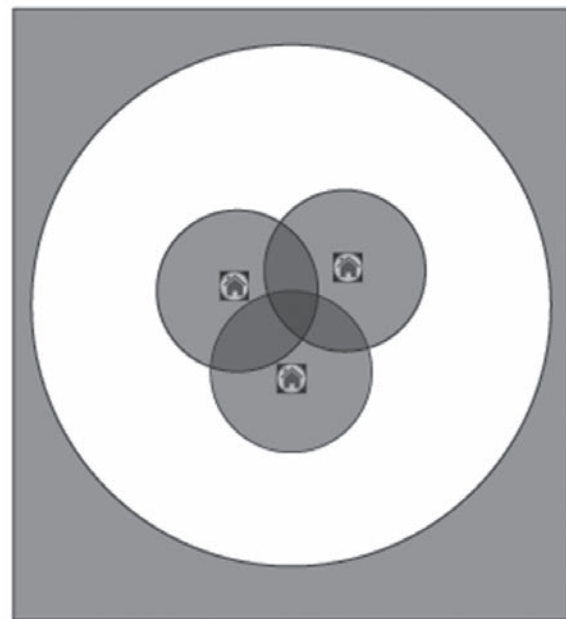
**Figure 1—Pre-Impact:** Assume that there is a large contiguous wilderness area which is largely non-impacted and inviolate. This is referred to as the “Blank Canvas”. For the purpose of the following geometrical demonstration, assume this wilderness area has the simple shape of a circle and that outside the area boundary are non-wilderness areas or areas with lower wilderness values. Hence:

- (i) Surface area of wilderness area =  $\pi R^2$
- (ii) Length of area boundary (which serves as an interface between wilderness and non-wilderness areas) =  $2\pi R$
- (iii) Maximum possible distance away from area boundary (and hence non-wilderness areas) =  $R$



**Figure 2—Initial impact:** Assume that one building is constructed on the “Blank Canvas”. Assume that the building has a simple equidistant impact on the wilderness area in all directions. Hence, the impacts of this one construction are:

- (i) diminishing the surface area of the wilderness from  $\pi R^2$  to  $\pi R^2 - \pi r^2$
- (ii) increasing the length of the interface between wilderness and non-wilderness areas from  $2\pi R$  to  $2\pi R + 2\pi r$
- (iii) decreasing the maximum possible distance away from area boundary from  $R$  to  $(R-r)/2$



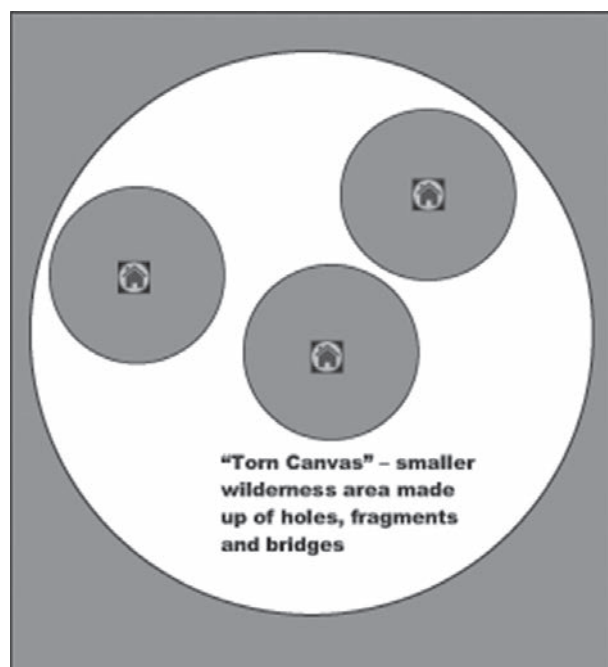
**Figure 3—Subsequent impacts – the “Holey Flag” effect:** Assume that two more identical buildings are constructed next to the first building. Impacts on the wilderness area will increase, but at a lower rate. For the 3 buildings, the total impacted area is less than  $3 \times \pi r^2$  and the increase in area boundary is less than  $3 \times 2\pi r$  because the impacted areas of the new constructions overlap with the area that has already been impacted by the first construction. The “hole” from the initial impact is enlarged. This demonstrates the “Blank Canvas” effect, i.e., that the first intrusion into a wilderness area has the largest relative impact.

overall cumulative impacts across the continent. Regardless of absolute scale, this emphasises the importance of detailed local scale modelling for all new developments in Antarctica, especially those in the wildest areas, to make sure that impacts are kept to an absolute minimum.

If new developments are built far apart, away from areas that are already impacted, their impacts on wilderness increase (Figure 4). They will cause the total surface area of the wilderness area to decrease, the length of the interface between wilderness and non-wilderness to increase, while within the wilderness area, the maximum possible distance away from non-wilderness reduces. Hence, the original contiguous wilderness area (or “Blank Canvas”), instead of being one large contiguous piece, becomes smaller and is made up of holes and smaller fragments connected through narrow sections (or “bridges”). In other words, it becomes a “Torn Canvas” (Figure 4).

## Scale Issues

Large contiguous natural areas are a global rarity. In a global analysis of protected areas, Leroux et al. (2010) concluded that the current global protected areas network



**Figure 4—Subsequent impacts – the “Torn Canvas” effect:**

If three buildings are built far apart within a wilderness area, then:  
 (i) the surface area of the wilderness diminishes to  $\pi R^2 - 3 \times \pi r^2$   
 (ii) the length of the interface between wilderness and non-wilderness areas increases to  $2\pi R + 3 \times 2\pi r$   
 (iii) the maximum possible distance away from area boundary falls below  $R$  or even  $R - r$  at many locations within the wilderness area  
 This demonstrates the “fragmentation” process. The original “Blank Canvas” becomes a “Torn Canvas” whereby the original large contiguous wilderness area becomes smaller, is split into smaller sections that are connected through bridges and where the maximum possible distance away from non-wilderness areas is reduced.

lacks large, strictly-protected areas with very low human footprint. The Antarctic wilderness is a unique treasure in this respect and so deserves the highest level of protection.

Scale is clearly one of the greatest challenges in mapping wilderness in Antarctica. The sheer size of the continent and the comparatively small and spatially confined human footprint means that a multi-scale approach is required to develop an adequate understanding of the spatial pattern of wilderness and remaining inviolate areas. At the scale of the whole continent, the best approach is perhaps to continue using maps showing the presence and scale of human features using symbols that are proportional to the size of the feature. Such an approach has limited utility however, because if the locations of research bases, etc. are shown to scale they will simply not be visible, thus giving a false impression of an entirely inviolate continent. At regional scales (e.g. the Antarctic Peninsula) more deterministic mapping techniques such as simple buffer zones can be used to show zones of human influence around roads, bases, airstrips, tourist landing sites, etc. At more local scales, such as for individual Antarctic Specially Managed Areas, complex and detailed models using the continuous and fuzzy data analyses such as those developed by Carver et al. (2012) for mapping wilderness in the Scottish national parks and Tricker et al. (2012) for mapping threats to wilderness character in the US national parks’ wilderness areas can be applied.

## Further Challenges

Moving on from the simple definition that wilderness is where there is an absence of human disturbance opens up further challenges for wilderness mapping in Antarctic. For example, permanent impacts such as from research bases and survey stations are obvious, but how do we handle the temporary or transient impacts associated with over flights, helicopter access, visits by tourist ships, etc? In many respects this is dependent on frequency (e.g. number of visits per year) and magnitude/scale (e.g. snow-cat supply convoy versus a lone skier) as well as potential cumulative effects (e.g. possible crowding of certain popular locations by cruise ships). Knowledge of visitation history and visitation rates will also affect the sense of wilderness in the most remote parts of the continent. While these issues are often not taken into account (or irrelevant) in the wilderness areas of more populated areas, Antarctica is one of the last few places on earth where inviolate lands are known to exist with any degree of confidence, so it is important that these remaining unvisited areas are kept inviolate as much as is reasonably practicable.

In Antarctica, like many high latitude polar regions, much of the biodiversity is found in the extremely productive marine environment. The biodiversity that exists on land tends to be located around the coastal margins and in the rare ice-free areas. Terrestrial biota is extremely fragile and sensitive to human impacts. Vegetation develops extremely slowly in the harsh climatic conditions meaning that physical impacts from human activities such as tire tracks, etc. last for many years. Here, human activities can have disproportionate ecological impact on wilderness. In areas that are covered in snow, rock and ice—over 98% of the Antarctic continent—biological



activity is generally very low. Here, human activities will have low ecological impact on wilderness. However, their landscape impact can be disproportionate, especially if it were the first human impact on to the “Blank Canvas” and leads to the subsequent fragmentation of a previously large contiguous wilderness.

Pollution is global and Antarctica is known to be affected. However, local sources of pollution will have the greatest and most noticeable effect. These include light pollution from research base lights, noise pollution from on-site operations and transport (e.g. from helicopters and skidoos), chemical pollution from exhaust fumes, etc. and the physical pollution from buildings, supplies and other infrastructure. Several detailed modelling tools are available to model spatial effects of light, noise and visual pollution.

In populated countries with a well-developed road network, it is usual to model remoteness based on travel time, on foot or other non-mechanised means, from nearest point of mechanised access (normally the road head). This is done using either simple buffer zones describing areas of equal accessibility or by more complex models that take intervening terrain, barrier features and land cover into account (Carver et al., 2013). In Antarctica, modelling the effects of distance, remoteness and accessibility will have to be based on operational ranges of helicopters and fixed wing aircraft, availability of landing sites together with terrain accessibility for land/ice based travel. Several detailed modelling tools are available to model remoteness and accessibility using a combination of buffer and anisotropic access models and these can be applied at a local scale to areas of operation in Antarctica.

## Conclusions and Ways Forward

Antarctica presents a number of challenges for the application of standard environmental management tools, such as wilderness mapping and EIAs focussed on wilderness values. The main challenges concern the size of the area relative to the extent of the human impact, and the fact that most human impacts are related to single sites or installations set in the context of a “Blank Canvas” with very little or no human impact. The sheer size and scale of Antarctica creates a problem for mapping in that the relatively small number and size of most bases and points of impact (e.g. flight paths, tourist landing points, etc.) mean that Antarctica appears almost wholly wilderness with a very high proportion of inviolate areas. Yet, the hitherto unspoilt and un-impacted nature of the region means that any human presence will have a disproportionately high impact relative to its size and context, especially in areas where there is no other human presence. This needs careful handling in such a way that wilderness mapping and EIAs do not hide or underestimate these effects.

At the Antarctic Treaty Consultative Meeting in 2013, the Wildland Research Institute (ASOC, 2013) recommended that the Antarctic Treaty Parties:

- Compile data on locations of human infrastructures and activities. Overlay the human footprint data on existing biogeographic domain maps of the Committee for Environmental Protection and the Scientific Committee on Antarctic Research.

- Develop a demonstration mapping project at three scales:
  - Continental Antarctica using simple, criteria-based mapping
  - Regional scale (e.g. for the Antarctic Peninsula) using index-based mapping
  - Local scale (e.g. James Ross Island) using local scale models

The recommendations received little concrete support, continuing the decade-long trend of the Treaty Parties’ lack of engagement on the issue of wilderness protection.

Despite the lack of interest from the Antarctic Treaty Parties, we continue to advocate for the need of a multi-scale modelling approach to map and monitor the scale, location and level of human activity in Antarctica as a key element in the implementation of the Parties’ legal obligation to protect Antarctica’s wilderness values. Clarity and the ability to zoom in to areas of interest (e.g. the holes in the “Blank Canvas”) to show greater detail is essential. This would allow managers and decision-makers to better understand the potential impacts of scientific, strategic and tourist developments in the region and thereby make provisions for minimising them through careful design, location and sharing of facilities, knowledge and timing of activities. While individual researchers and research institutes, including the Wildland Research Institute can take the lead and take on the task of developing new technologies and models, the active engagement of Antarctic Treaty Parties and their National Antarctic Programs are fundamental and indispensable. They need to provide access to the appropriate data on human activities, participate in a coordinated mapping effort and use the output in their planning activities to achieve on-the-ground protection of the Antarctic wilderness. Protection of the Antarctic wilderness will only be a reality if there is genuine commitment from Treaty Parties and their National Antarctic Programs to make it happen.

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