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Impact of Human Activities on the Terrestrial Ecosystem of Antarctica: A Review

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Abstract: An awareness of human impacts on the Antarctic terrestrial ecosystem has been increasing in the recent decades due especially to the expansions of scientific expeditions and the tourism industry. In this review, localized contamination of soils and vegetation, disturbance of wildlife, import of alien organisms as well as introduction of exogenous bacterial diseases as a result of human activities undertaken in Antarctica have been outlined. Besides, potential threats to the Antarctic environment from the contaminants emanating from sources outside the Antarctic have also been demonstrated. Finally, efforts and progresses within the Antarctic Treaty System towards protection of the Antarctic environment and its terrestrial ecosystem are briefly summarized in this review.

Zusammenfassung: In den letzten Jahrzehnten sind menschliche Einflüsse auf terrestrische Ökosysteme der Antarktis infolge expandierender Forschungsaktivität und des Tourismus stark angestiegen. In diesem Überblick werden lokale Kontaminationen von Böden und Pflanzen, Störungen der Wildtiere sowie Importe fremder Organismen und Krankheiten dargestellt. Auch potentielle Bedrohungen der antarktischen Umwelt durch eine mit anthropogenen Schadstoffen belastete Atmosphäre werden erläutert. Schließlich wird zu den Bemühungen eines Schutzes der antarktischen Umwelt und ihrer terrestrischen Ökosysteme im Rahmen des internationalen Antarktisvertrages Stellung genommen.

INTRODUCTION

Antarctica is believed to have suffered much fewer adverse influences of human activities in comparison with the rest of the world, due to its geographical remoteness and climatic hardships (ABBOTT & BENNINGHOFF 1990, WOLFF 1990, BONNER 1994). However, alongside a considerable expansion of scientific expeditions and their supporting logistics as well as a remarkable increase of tourism and non-governmental activities, the environmental conservation of Antarctica is now becoming an urgent issue and receiving more and more attention (BONNER 1990, CAMPBELL et al. 1994).

It is well known that organized polar expeditions began earlier than environmental protection was popularly concerned. The preservation and protection of the Antarctic environment was rarely mentioned when the Antarctic Treaty was negotiated and signed in the late 1950's (MACHOWSKI 1992, BONNER 1994). Since then, the interest in Antarctica has been steadily growing and more and more nations have become involved in Antarctic research. Scientists and support personnel have become most numerous. There were around 900 scientists and supporting staff wintering over in Antarctica, and 3,000 were at work in the austral summer of 1985. Since the early 90's, summer expeditioners and supporting personnel alone have numbered up to 5,000 (GJELSVIK 1985, STONEHOUSE 1992). An estimate of the number of people-days spent in the whole of the Antarctic for science was made, which showed there were around 629,255 science and logistic days during the 1992 winter and the 1992-1993 summer (AUSTRALIAN ANTARCTIC DIVISION, unpubl. information 1993). A substantial growth in scientific expeditions resulted in the setting up of numerous stations, settlements, camps and field refuges in Antarctica. Now, the year-run stations alone have been numbered at more than 40, operated by nearly 20 countries (HEADLAND & MERRINGTON, unpubl. information). It has never been doubted that Antarctic station operations have always been accompanied by local environmental problems, and as a result of concentrated activities such as power generation, waste disposal, vehicle use, fuel management, and airstrip and road construction, the areas around stations suffered much more human impact than other regions of the Antarctic (WOLFF 1990, HARRIS 1991a, MACHOWSKI 1992).

Besides scientific activities, now tourism is bringing new threats to the Antarctic environment and causing a special concern from related authorities. Although it has only been since the late 50's that Antarctica became a tourist destination, by 1991 approximately 39,000 tourists are estimated to have visited Antarctica. The fact that, of the total tourists, more than 40 percent had travelled during the period from 1985 to 1991, demonstrated a quickened growth of Antarctic tourism due to more convenient transportation of the scheduled commercial cruisers and flights (Fig. 1) (ENZENBACHER 1992, STONEHOUSE 1992). For example, the Polish Arctowski Station received more than 5,000 people between December 1991 and February 1993 (DONACHIE 1993). In the 1994 Antarctic summer, the number of tourists was more than double that of the summer scientific population (ROURA & FAIRLEY 1995). The impact of tourist activities on the Antarctic environment is very difficult to measure with certainty and, to date, no comprehensive and systematic tourism impact assessment has been undertaken (ENZENBACHER 1992). However, a number of investigations reported from the attracting tourist destinations showed that, to a certain extent, the tourists were responsible for the consequences of wildlife disturbance, vegetation trampling and material import as well as other impacts on the environment (e.g. THOMSON 1977, CULIK et al. 1990, HARRIS 1991b, MACHOWSKI 1992, WOEHLER et al. 1994). A preliminary field study of tourist visits and movements, which was made by a special team on

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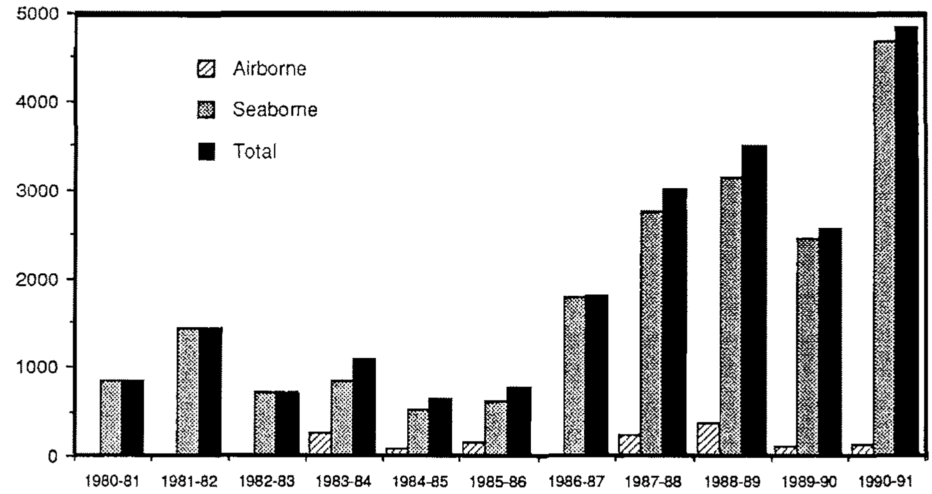

Fig. 1: Estimated number of tourists in Antarctica in the period of 1980/81 to 1990/91 (from ENZENBACHER 1992).

Abb 1: Zahl der Flug- und Seetouristen in der Antarktis von 1980 bis 1991 (nach ENZENBACHER 1992).

the South Shetland Islands and Antarctic Peninsula, indicated that the potential for harm by ill-disciplined tourist groups was great, and possible effects on ecosystems must be taken into account in assessing total impact (STONEHOUSE 1992).

Although Antarctica is physically remote from the other continents, its environment could be affected by human activities undertaken elsewhere in the world. The strongest evidence of pollution reaching Antarctica came from radioactive debris detected in ice cores since the atmospheric tests of nuclear bombs and the operation of nuclear power plants in the world (PICCIOTTO & WILGAIN 1963, JOUZEL et al. 1979, POURCHET et al. 1983). Another sound example for this was provided by the detection of organochlorine pollutants, which emanate from industrial and agricultural productions, in Antarctic ice and snow and wildlife as well (SLADEN et al. 1966, BREWERTON 1969, CONROY & FRENCH 1974, LUKOWSKI 1983). In addition, there is a growing concern for exogenous and invading biota, whose propagules are believed to arrive in Antarctica through several methods and establish themselves in various degrees (RUDOLPH & BENNINGHOFF 1977). The impact on Antarctic ecosystems and the damage to native communities caused by competition and adaptation of the invading organisms have been little studied so far.

It has never been doubted that the pristine environment of the Antarctic needs to be maintained, not only for the protection of Antarctica itself, but for the protection of the whole planet, especially since the great realization of the intrinsic value of the Antarctic as a scientific laboratory, and of its extrinsic value as a principle controller of world climate (BONNER 1990, MACHOWSKI 1992). The Antarctic constitutes the last natural terrestrial ecosystem to be invaded and modified by human beings (RUDOLPH & BENNINGHOFF 1977, BONNER 1990). Whereas historically a significant change has arisen in the Antarctic marine ecosystem as a result of Man's exploitation of whales and seal, human impacts on the terrestrial ecosystem, including the inland water ecosystem, remains very slight. However, the Antarctic terrestrial ecosystem is probably the simplest and most fragile in the world because of the exceedingly harsh conditions (RUDOLPH & BENNINGHOFF 1977, FIFIELD 1987, CLARIDGE et al. 1995). Having little capacity to withstand human interference and having slow biological processes on very small scales, the Antarctic terrestrial ecosystem is easily disrupted or perturbed, and much more difficult to rehabilitate than ecosystems in other parts of the world (BOCZEK 1985, FIFIELD 1987). Although it has been generally accepted that the adverse influences of human activities on the Antarctic terrestrial ecosystem are limited and localized, numerous studies failed to present an optimistic view about the future.

This review aims to outline the problems covering the most important topics of human impact on the terrestrial ecosystems of Antarctica through the available information and data and to summarize the efforts and progress within the Antarctic Treaty System dealing with the adverse influences of human activities in Antarctica.

LOCALIZED IMPACTS ON ENVIRONMENTAL CONDITIONS

Of greatest concern to the environmental conditions are management practices employed to cope with increasing densities of human population at scientific stations (CAMPBELL & CLARIDGE 1987). Most stations and bases in Antarctica have a high probability of causing adverse influences on the terrestrial ecosystem not only because of their power generation, waste disposal, vehicle use, material importing etc., but also due to their localization often at coastal ice-free areas which are also favourable to biological communities (FIFILED 1987, CULIK et al. 1990). As a result, many investigations focussing on environmental issues have been carried out in the vicinities of scientific stations at various localities in Antarctica, demonstrating an alarming level of localized contamination of environmental conditions.

Contamination and physical destruction of soils

To provide a measure of the extent to which the disturbance to the local environment by human activities may have taken place, little quantitative information has been available until now.

Amongst human disturbance to soil environment, soil pollution by anthropogenic organic and inorganic matters received earlier attention. Fahy (1978) reported the occurrence of severe aluminum pollution in the vicinity of Scott Base on Ross Island, Antarctica. In the McMurdo Sound region, soil samples from several sites contaminated by human activities were examined for heavy metal contents by Claridge et al.(1995). Lead, zinc and copper were found in soils close to the point sources such as crushed batteries, scattered rubbish and buildings. A similar study was earlier conducted around Vanda Station by Sheppard et al. (1994) and demonstrated a comparable extent of heavy metal contamination in the soils. According to Claridge et al. (1995), traces of heavy metal contamination arising from human activity could be detected in Antarctic soils. The levels found were not considered to represent serious pollution, but indicated that human activities could change the chemistry of the Antarctic environment in localized areas.

In order to ascertain the extent of hydrocarbon contamination emanating from fuel storage facilities and other potential sources in scientific stations, soil samples from selected locations at Casey Station on Prydz Bay, at Signy Station, South Orkney Islands, and at Palmer Station on the Antarctic Peninsula were analyzed respectively by Green & Nicholas (1995), Cripps (1992) and Kennicutt et al. (1992). As a result, various levels of *n*-alkanes (major composition of hydrocarbon) and polycyclic aromatic hydrocarbons (PAH, indicators of contamination from anthropogenic sources) were detected in all samples involved in the above studies. In the late 80's, up to 62 million liters of fossil fuel were estimated to be used for station operations in Antarctica every year. About 0.1-1 % of that fuel was believed to spill as a matter of routine, and more in accidents (Roura & Fairley 1995). Besides the contamination from leaking oil near storage tanks and drums, the events of fuel spills reported from Amundsen-Scott, Casey and McMurdo Sound stations had highlighted more serious threats to soil environments associated with the management and use of oil fuels in Antarctica and caused a growth of concern (Antarctic 1989, 1990; Wilkniss 1990, Harris 1991).

In comparison with accumulations in soils of heavy metals, hydrocarbons, etc., physical disturbances to the soils and underlying permafrost by construction activities and vehicle uses at and near scientific stations in Antarctica are more common and more serious. The extent of impacts on soil from vehicles was illustrated by Harris (1991a) who showed in his observations that damage to soils and vegetation from tracked vehicles was evident, even severe on King George Island, South Shetland Islands, particularly around Bellingshausen Station, where slopes had been severely eroded and tracks had penetrated to a depth of 0.5 m. Drainage patterns had been altered and quagmires formed. An investigation of soils and underlying permafrost from sites disturbed by construction activities at Marble Point and Pram Point in the McMurdo Sound region was conducted by Campbell et al. (1994), and suggested that the release of considerable water content from the permafrost as a result of land disturbance caused stream flows, soil shrinkage, and land slumping and salinization, resulting in significant permanent environment damage.

Air pollution and damage to vegetation

Whereas accumulation in soils of the contaminants derived from human activities could only be detected at and near the selected sites at scientific stations where there were obvious evidences of disturbance and contamination, the concentrations of airborne pollutants of local emissions from the year-round stations, mainly as a result of fuel and waste combustion, could be determined in surface snow, even at 10 to 100 km from the sources (Boutron & Patterson 1987, Boutron & Wolff 1989).

Available data on fuel and waste combustion suggested that emissions of sulphur and most metals could be important in local areas only. For lead, the emissions were about 1,800 kg a^{-1}, which was about 20 % of the total fallout of lead to Antarctica each year (Boutron & Wolff 1989, Wolff 1990). In the Admiralty Bay region, the total amount of substances transported from the atmosphere was estimated at 12.7 t km^{-2} per year, whereas the amount from precipitation was about 2.5 t km^{-2} (Pecherzewski 1987). Also on South Shetland Islands, an earlier research on air pollution with sulphur dioxide and fluorine compounds carried out by Molski et al. (1981) showed that, although the levels of SO_2 and fluorine compounds at Arctowski Station were rather low, their accumulation was significantly higher than other examined sites at distance.

It is well known that airborne pollution brings considerable damage to the terrestrial flora of Antarctica, especially to lichens, which form dominant communities of ground vegetation in many ice-free areas of Antarctic, due to the great ability of their thalli to accumulate inorganic ions from the air (Harris & Kershaw 1971). The influence of air pollution on lichen *Usnea antarctica* had been illustrated by Olech (1991) whose study indicated, at Arctowski Station, that the concentrations of trace metals in thalli of lichen near the incinerating plant of the station were several to tens times higher than that found in the thalli of healthy lichens distant from station area. At Casey Station, Wilkes Land, Adamson & Seppelt (1990) demonstrated the airborne alkaline pollution damage to lichens and pointed out that the lichens (*Umbilicaria* and *Usnea*), which had been affected by the air pollution from a concrete batching site, had considerable lower chlorophyll contents, only one-half and two-third of that of healthy lichens in the ISSS area respectively. Meanwhile, in this study, there was evidence indicating that the polluted lichens suffered damage to the photosynthetic apparatus. In the study conducted by Roser et al. (1992) on Bailey Peninsula, Windmill Islands, Budd Coast, levels of polyhydric alcohols and oligosaccharides in the lichens *Umbilicaria decussata* and *Usnea sphacelata* were measured in samples from the sites severely polluted by alkaline cement dust derived from concrete mixing activities, the obtained results showed that the polluted lichens

Country	Station No	Name	Locality	
Argentina	6	Esperanza, Hope Bay*	63.40°S	56.98°W
		General Belgrano II, Coats Land*	77.87°S	34.63°W
		General San Martin, Barry Island*	68.13°S	67.07°W
		Orcadas, Laurie Island	60.75°S	44.73°W
		Teniente Jubany, King George Island*	62.23°S	58.67°W
		Vicecomodoro Marambio, Seymour Island*		
Australia	4	Macquarie Island	54.50°S	158.95°E
		Casey, Vincennes Bay*	66.28°S	110.53°E
		Davis, Ingrid Christensen Coast*	68.57°S	77.95°E
		Mawson, Mac Robertson Land*	67.60°S	62.89°E
Brasil	1	Comandante Ferraz, King George Island*	62.08°S	58.40°W
Britain	4	Bird Island, South Georgia	54.00°S	38.05°W
		King Edward Point, South Georgia	54.28°S	36.48°W
		Halley, Brunt Ice Shelf*	75.58°S	26.73°W
		Rothera, Adelaide Island*	67.57°S	68.12°W
Chile	3	Pres. Eduardo Frei Montalva, King George Isl.*	62.21°S	58.97°W
		Capitan Arturo Prat, Greenwich Island*	62.48°S	59.68°W
		General Bernardo O'Higgins, Cape Legoupil*	63.32°S	57.90°W
China	2	Great Wall, King George Island*	62.22°S	58.97°W
		Zhongshan, Princess Elizabeth Land*	69.37°S	76.42°E
France	4	Port-aux-Francais, Iles Kerguelen	49.35°S	70.20°E
		Alfred-Faure, Iles Crozet	46.43°S	51.87°E
		Dumont d'Urville, Terre Adelie*	66.67°S	140.02°E
		Martin deVivies, Ile Amsterdam	37.83°S	77.57°E
Germany	1	Neumayer, Ekströmisen*	70.65°S	8.25°W
India	1	Martri, Shirmacheroasen*	70.75°S	11.73°E
Japan	2	Syowa, Ongul*	69.00°S	39.58°E
		Dome Fuji, Valkyrjedomen*	77.32°S	39.72°E
New Zealand	1	Scott Base, Ross Land*	77.85°S	166.02°E
Poland	1	Henryk Arctowski, King George Island*	62.17°S	58.48°W
Russia	4	Bellingshausen, King George Island*	62.20°S	58.97°W
		Mirny, Queen Mary Land*	66.55°S	93.02°E
		Molodezhnaya, Enderby Land*	67.67°S	45.85°E
		Novolazarevskaya, Princesse Astrid Kyst*	70.77°S	11.83°E
South Africa	3	Gough Island	40.35°S	9.87°W
		Marion Island	46.87°S	37.85°E
		SANAE, Kronprinsesse Martha Kyst*	70.30°S	2.37°W
South Korea	1	King Sejong, King George Island*	62.23°S	58.78°W
Ukraine	1	Academician Vernadskiy, Argentine Island*	65.25°S	64.27°W
United States	3	Amundsen-Scott, South Pole*	90°S	
		McMurdo, Ross Land*	77.85°S	166.62°E
		Palmer, Anvers Island*	64.77°S	64.08°W
Uruguay	1	Artigas, King George Island*		

Tab. 1: Antarctic winter stations in 1996; * indicates stations located in the Antarctic Treaty Area, after HEADLAND & MERRINGTON, unpubl. information, 1996.

Tab. 1: Antarktische Winterstationen 1996. * = stationiert innerhalb des Gebites des Antarktisvertrages; nach HEADLAND & MERRINGTON, unveröff. 1996).

possessed significantly lower levels of these intracellular constituents than unpolluted lichens (Tab. 2).

HUMAN DISTURBANCE TO WILDLIFE

The fauna of Antarctica presents a remarkable contrast between the land and the surrounding sea, while the number of animals on the continent is extremely low, there are tens of millions of marine birds, mostly various species of penguin, but also skuas, petrels, shags, terns, gulls and other avifauna. Of the mammals, various species of seal are free to feed and breed in the coastal areas (BOCZEK 1985, MACHOWSKI 1992). Due to the expansion of human activities, the disturbance to wildlife in Antarctica has been described frequently.

Human activity has been known to exert its influence on wildlife in various ways. Impact on physiology, destruction of territory and habitat, disturbance of food chains, even direct and indirect egging and killing could all result in the short- or long-term changes in populations, breeding success, and distribution patterns of wildlife.

Population changes

Different species of wildlife are widely diverse in their responses to human disturbance. Giant petrels, a particularly sensitive species, according to HARRIS' (1991) observation on King George Island, South Shetland Islands, had abandoned their nests close to a new station following its construction. On Ardley island, close neighbor to King George Island, where the populations of wildlife were extremely exposed to disturbance from aircraft, vehicles, scientists and tourists, an 80 % decline in the giant petrel population had been reported by SCAR in 1991 (HARRIS 1991).

Adélie penguins (*Pygoscelis adeliae*), a most-studied species in Antarctica, although seeming unconcerned, react strongly to human disturbance (CULIK et al. 1990, WILSON et al. 1991). The population figures in an investigation by THOMSON (1977) on an Adélie penguin rookery at Cape Royds on the western shore of Ross Island showed that the chances of the survival of the rookery seemed less than marginal after a period of some years of uncontrolled visitor activity. After the restrictions on man's activities in the designated area of rookery, an immediate increa-

Lichen	Sample	Degree of pollution	Moisture content %	Ignition loss %	Polyols + sugar (mg g^{-1} dry wt)	Chlorophyll *a* content (mg g^{-1} dry wt)
Umbilicaria decussata	SSSI 16 site 1	-	10.3	90	36±1.4	0.75±0.6
	SSSI 16 site 2	-	21.6	90	30±1.6	0.53±0.2
	South Hill	-	21.3	96	34±2.9	0.59±0.3
	90 m Downwind[a]	+	12	92	12.5±0.1	0.42±0.3
	90 m Downwind[b]	+	19	98	25.0±1.5	0.44±0.2
	90 m Downwind[c]	+	34	99	19.5±2.2	0.51±0.2
	Laboratory site	+	28.9	95	18.9±1.2	0.44±0.2
	10 m Downwind[a]	++	13	96	1.1±0.2	0.08±0.3
	10 m Downwind[b]	++	20	94	3.2±0.1	0.19±0.3
	10 m Downwind[c]	++	20	96	5.5±0.3	0.15±0.1
Usnea sphacelata	SSSI 16 site 1	-	10	99.5	17.2±1.0	0.20±0.2
	90 m Downwind[a]	+	9	92	19.0±0.4	0.32±0.1
	10 m Downwind[a]	++	10	89	8.4±0.4	0.14±0.1

Tab. 2: Differences of total levels of polyhydric alcohols and sugars in the polluted and healthy lichens (from ROSER et al. 1992).
Distance downwind refers to distance downwind of concrete mixing plant. „South Hill" refers to a lichen-rich ridge 100 m due south of the Casey Station Domestic Building. „Laboratory site" refers to site of temporary container laboratory located at the eastern end of the new station and subject to previous cement dust and present road dust contamination. Figures given for „polyols + sugars chlorophyll *a*" are mean ±1 standard deviation. Pollution categories were subjectively assessed as healthy looking plants in unpolluted areas (-), plants in varying degrees of health in areas with recognizable human pollution (+), and plants in poor conditions as indicated by loss of pigment (++). The polluted site designations ([a]), ([b]), and ([c]) refer to three parallel transects 10 m apart running downwind from the concrete mixing area.

Tab. 2: Gesamtgehalte von durch mehrwertige Alkohole und Zucker belasteten und gesunden Flechten (nach ROSER et al. 1992).

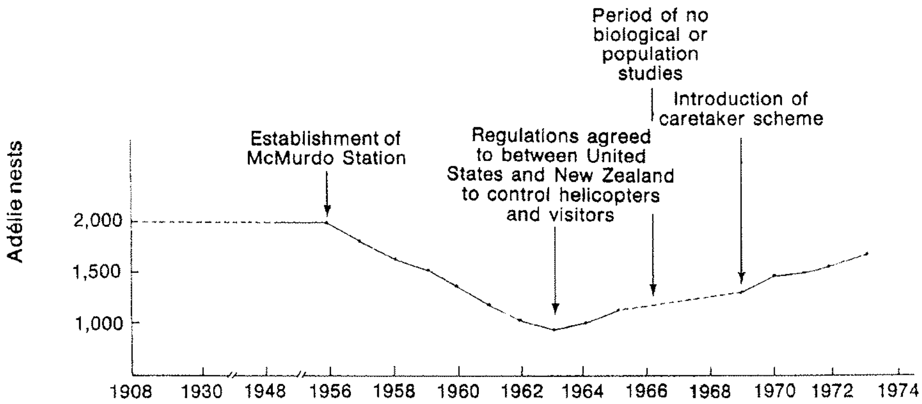

Fig. 2: Change of number of Adélie breeding pairs at Cape Royds (from THOMSON 1977).

Abb. 2: Änderungen der Adélie-Pinguin-Population (Zahl der Brutpaare) auf Cape Royd (nach THOMSON 1977).

se in the numbers of breeding pairs, which were closely correlated to the degree of disturbance, was recorded (Fig. 2), but it took a period of 12 to 14 years to attain the pre-decline population. A similar situation of changes in Adélie penguin populations was observed at Cape Hallett. During human occupation in the joint US-NZ base for years, the number of penguins breeding at Cape Hallet had declined due to both disturbance and loss of breeding habitat and it was also 12 to 14 years after Hallett Station was abandoned that penguins reached their pre-decline level (FREDRICKSON 1971, WILSON et al. 1990).

Unlike penguins and petrels, skuas appear to have a great ability to tolerate human disturbance. Whereas populations in other birds had decreased under the influences of human activities, populations in skuas could be maintained despite long-term proximity to human activity, even increased due in part to dumps of human food wastes at some stations (HEMMINGS 1990, YOUNG 1990, WANG et al. 1996).

Breeding success

According to observations on the behavior of Adélie penguins undertaken by CULIK et al.(1990), man-made stimuli during the breeding season could result in a significantly reduced breeding success (chicks fledged per nest) of penguins.

Studying breeding success of Adélie penguins at two localities near Casey Station, Shirley Island and Whitney Point, WOEHLER et al. (1994) found that the breeding success was significantly lower for Shirley Island colonies than for those at Whitney Point which were within the Site of Special Scientific Interest Area, and that those of the breeding populations colonies were free of disturbance, despite their proximity to Casey Station. It was believed that human visitors from Casey were responsible for the observed reduction of breeding success for the colonies on Shirley Island (WOEHLER et al. 1994). The reduced breeding success in the Antarctic skua (*Catharacta maccormicki*) territories had been reported from the eastern Larsemann Hills, Princess Elizabeth Land, although skuas proved to be largely unaffected by human-induced environmental disturbance (WANG & NORMAN 1993a, WANG et al. 1996).

Disturbance to balances among species

As it is well known, for preservation of wildlife, the stability of distribution patterns of species under natural conditions must be maintained. An increase or decrease in populations of some species through human disturbance might result in a change in numbers of other species.

During the examination of the skua population at Hallett Station, JOHNSTON (1971) found a decline of skua numbers over a long-term period, and the decrease of skuas had a correspondence with a decline of Adélie penguin population, which resulted directly from human activity. It was noted to be important to maintain the balance between penguins and skuas from conservation penguin breeding colonies at Cape Crozier (OELKE 1978). Young's field investigation on Cape Bird, Ross Land also suggested that the falloff in the numbers of penguins at some colonies had been caused by the depredations of the skuas there (YOUNG 1990). On the other hand, at Signey Island, although skuas do not feed exclusively on penguins, some increase in skua numbers might have been expected as a result of the increased penguin numbers (HEMMINGS 1990).

IMPORTING OF ALIEN ORGANISM

It would be expected that the remoteness and isolation of Antarctica could have protected its terrestrial ecosystem from invasions of exogenous organisms. However, more and more evidences were found that Antarctica is receiving a steady biological import from the other parts of the world in various ways. Amongst those, long-distance drifts of pollen and spores by wind, especially by westerly winds from the neighbouring landmasses and islands play the most important role, and transport of larger propagules is believed to be mainly carried out by sea birds (SMITH 1984, BROADY et al. 1987, KAPPEN & STRAKA 1988). However, humans appear to be also responsible for the dispersal of alien organisms to Antarctica as a result of such activities as the importing of meat and poultry products as well as vegetables, and the introduction of foreign plant species and domestic animals. Even humans themselves are believed to be effective vectors for alien microorganisms dispersal and for some bacterial diseases (HARRIS 1991, BROADY & SMITH 1994, KERRY & CLARKE 1995).

Although there are many endemic terrestrial species, only very few endemic genera have been found in Antarctica. According to RUDOLPH & BENNINGHOFF (1997), the cosmopolitan organisms with high survivability under extremely unfavourable conditions such as low and fluctuating temperatures available elsewhere in the world could theoretically be potential invaders, and „they only need a way to get to Antarctica".

Micro-Organisms Introduced into Soils

Microbiology of Antarctic soils has been intensively studied and the results indicate that most of the microbiota in the Antarctic soils are cosmopolitan and they also could be expectedly found in the other parts of world (HEAL et al. 1967, BAKER 1970, BAKER & SMITH 1972, RUDOPH & BENNINGHOFF 1977, TEARLE 1987, BROADY 1984, BROADY et al. 1987, VISHNIAC 1993, BROADY 1993). This reasonably suggests that Antarctic soil ecosystems could easily suffer the contamination by exogenous microoganisms.

It was not surprising that many of the alien microbiota found in Antarctic soils were believed to derive from human activities, in particular the thermophilic bacteria reported by numerous investigators (e.g. LACY et al. 1970, CAMERON et al. 1972). For example, as early as the 60's, BOYD et al. (1966) noted the common soil organism contamination in the vicinity of human activities and the relative high numbers of thermophilic bacteria in the soils around some populated areas in the Antarctic (BOYD & BOYD 1963, BOYD et al. 1966). Some species of fungi, especially microfungi, in Antarctic were present in soils also due to human introductions. In a more recent study undertaken at Scott Base, Ross Land by BROADY & SMITH (1994), the sample materials taken from dust on the equipment and boots of expeditioners prior to their leaving for Antarctica, and from soil adherent to the imported fresh vegetables were detected and a total of 50 taxa, mostly typical soils algae, were identified as potential colonizers, amongst which 10 taxa were from genera unrecorded in the Ross Sea regions. Although there was no evidence of the establishment of any exogenous algae imported by humans in Scott Base, doubtless, these potential colonizers could pose a threat to the existing local soil ecosystem. In Antarctica, amongst the ice-free area there is some warm ground heated by volcanism, such as the sites on South Sandwich Islands and South Sheltland Islands Island in maritime Antarctica, and the areas near Mt. Erebus on Ross Island, Mt. Melbourne in Northern Victoria in continental Antarctica (NATHAN & SCHULTE 1967, LYON & GIGGENBACH 1974, LONGTON & HOLDGATE 1979, BROADY et al. 1987, BROADY 1993), where it was believed that a favourable environment is present for establishment and growth of organisms typical of more temperate regions. According to BROADY (1993), the human activities within these areas should be carefully controlled to minimize the new introductions of alien organisms by means of contaminated clothing, boots, and scientific apparatuses. In fact, the vegetation of the thermal ground on South Shetland Islands has been seriously perturbed due to intensive logistic, scientific and tourist activity. Also on Deception Island, the sites of warm ground have suffered damage (SMITH 1988).

Introduced Diseases

Imported meat and poultry products, introduced domestic animals in the populated stations as well as humans themselves, to some extent, could possibly be threats to Antarctic living systems as effective or potential vectors for bacterial disease.

In 1979 PARMELEE and his co-worker reported that, at Palmer Station, as a result of an outbreak of fowl cholera, tens of brown skuas were estimated to have died (PARMELEE et al. 1979). A sharp decline of subantarctic skua in Admiralty Bay on George King Island in a short period was due, at least partly, to introduction of disease through human activities (TRIVELPIECE et al. 1981, HEMMINGS 1990). KERRY & CLARKE (1995) in a recent review pointed out that penguins were suffering some diseases unrecorded in the wild, and the same situation probably applied to Antarctic seals. „Adélie penguins in Antarctica have been shown to have antibodies to Newcastle disease virus, avian influenza virus and the Chlamydia group of Bacteria". Although, „there is no evidence to date that any major exotic diseases have been introduced into the Antarctic ecosystem", „...Humans themselves may also be possible vectors for bacterial diseases," according to KERRY & CLARKE (1995).

THREAT OF CONTAMINANTS FROM SOURCES OUTSIDE ANTARCTICA

Except for localized areas around the populated stations and bases, the extent of environmental contamination was not considered to have caused direct damage to the terrestrial ecosystem. Therefore, the pollutants detected in Antarctic ice and snow, emanating from distant sources in the other continents, were generally considered as the indirect indicators of global-scale pollution in the atmosphere rather than as the signals of contamination of the Antarctic environment (WOLFF 1990). However, announcements on accumulation of organochlorine compounds in Antarctic wildlife received wide attention (RISEBROUGH 1977).

Contaminants in Ice and Snow

For heavy metal accumulations in Antarctic snow, the reliable data suggested that while increases of concentration of Cu and Zn were estimated to be small, even negligible (VÖLKENING & HEUMANN 1988, WOLFF 1990), the concentration for Pb (ranging from 2-7 ng kg^{-1}) in some regions of Antarctica had an increase of 5 to 20 fold over recent decades (including probable attribute from local emissions of scientific stations) (WOLFF & PEEL 1985, BOUTRON & PATTERSON 1987). For organic pollutants, several kinds of compounds of chlorinated hydrocarbons (DDT, HCH, PCB), which were known as excellent indicators of pollution, had been detected in Antarctic snow (PEEL 1975, RISEBROUGH at al. 1976, TANABE et al. 1983). Although no significant increases over the last few decades, pollution-derived changes in nitrate and sulphate had been detected in Antarctic snow (LEGRAND & DELMAS 1986, MULVANEY & PEEL 1988, WOLFF 1990). As a result of nuclear bomb tests and nuclear plant operations, total b-radioactivity and tritium level in the ice and snow at South Pole had been tens times greater than that of the pre-nuclear periods (PICCOTTO & WILGAIN 1963, JOUZEL et al. 1979, KOIDE et al. 1982).

Organochlorine Residues in Wildlife

Since the first announcement on detection of DDT residues in Antarctic wildlife, a variety of organochlorine pesticides and their derivatives has been found in numerous species of sea birds and mammals in various regions of Antarctica (e.g. GEORGE & FREAR 1966, SLADEN et al. 1966, TOTTON & RUZICKA 1967, RISEBROUGH & CARMIGNANI 1972, RISEBROUGH 1977).

In the initial studies, accumulation of organochlorine residues in wildlife were considered a result of localized contamination caused by the operations of scientific stations, but this was refuted by the failure to find PCB residues in many involved samples which should have much higher levels than DDT compounds in the refuse of stations (RISEBROUGH 1977, LUKOWSKI 1983). At present, organochlorine pollutants are commonly recognized to reach Antarctica through the atmosphere from distant sources of contamination elsewhere in the world (RISEBROUGH 1977).

Most of the findings of accumulation of DDT and its metabolites in Antarctic animals occurred in the 60's when DDT-containing biocides were being used all over the world, but the residues with similar levels were detected even in the 80's when DDT had been withdrawn from general use for years (LUKOWSKI 1983, 1993). In view of the above-mentioned fact, further studies focussing on dynamic change of organochlorine residues are needed.

So far, data on the accumulation of organochlorine pollutants from the sources of the other continents on Antarctic soils, vegetation, and inland water have not been available.

CONSERVATION OF ANTARCTIC ENVIRONMENT AND ITS ECOSYSTEMS

While the universal, regional and bilateral agreements become effective in some cases, most of the provisions for the preservation and protection of the Antarctic environment are generally provided by the Antarctic Treaty System (ATS), which comprises the Antarctic Treaty, the Agreed Measures for Conservation of Antarctic Fauna and Flora, conventions on the Conservation of Antarctic Marine Living Resources (CCAMLR) and Conservation of Antarctic Seals (CCAS), as well as the numerous recommendations adopted at the Antarctic Treaty Consultative Meetings (ATCMs) (HEAP 1990, HARRIS 1991b). In the more than 30 years since the Antarctic Treaty was signed and came into force, ATS has proved to be responsive to the conservation of the Antarctic environment (BONNER 1990, 1994). A majority of some 200 ATCM recommendations was known to deal with, or be related to, the preservation and protection of the Antarctic environment and its ecosystem (MACHOWSKI 1992). The conservation of the Antarctic terrestrial ecosystem is involved in a number of these recommendations.

Since the III ATCM in 1964, when the provision was provided to designate Special Protected Areas (SPAs) in order to protect the „unique natural ecological systems", a variety of protected areas and sites such as Sites of Special Scientific Interest (SSSIs), Specially Reserved Areas (SRAs), Multiple-Use Planning Areas (MPAs), Antarctic Specially Protected Areas (ASPAs), Antarctic Specially Managed Areas (ASMAs) etc. have been designated and now a comprehensive Antarctic Protected Areas System (APAS) with precise conservation rules has been formed.

At the VIII ATCM 1975, based on a response by the Scientific Committee on Antarctic Research (SCAR), an important recommendation was provided as Code of Conduct for Antarctic Expeditions and Station Activities. The code consisted of four parts, dealing with waste disposal, drawing attention to existing provisions of the Agreed Measures and anticipating the provision of environmental impact assessment, etc. At the same ATCM the increasing effect of tourism and non-governmental activities on the Antarctic environment had been concerned, and the related recommendation (VIII-9) called upon all visitors who entered the Treaty Area for an awareness of a Statement of Accepted Practices and the Relevant Provisions of the Antarctic Treaty, which were contained in an Annex to the recommendation. At the following X ATCM in 1979, Guidance of Visitors to the Antarctic was adopted (HEAP 1990, BONNER 1990).

Impact of human activities on the Antarctic environment has become an important issue for discussion at ATCMs since the Sixth. In 1983, Recommendation (XII-3) adopted at the XII ATCM called on SCAR to provide advice on the scientific and logistic activities with an actual or probable significant impact on the environment. In 1987 the XIV ACTM passed the recommendation calling for the evaluation of environmental impact in the planning process of scientific research programmes and their associated logistic support activities (Recommendation XIV-2), Within the Recommendation a two-step process known as the Initial Environmental Evaluation (IEE) and Comprehensive Environmental Evaluation (CEE) would be carried out (BONNER 1990, HEAP 1990).

The adoption of the Protocol on Environmental Protection to the Antarctic Treaty (together with its four annexes) at the XI Special ATCM In 1991 marked the establishment of a comprehensive, legally binding regime for conservation of the Antarctic environment and its dependent and associated ecosystems (MACHOWSKI 1992). According to the Protocol, all activities in the Antarctic have to be planned and conducted so as to limit adverse influences on the environment and to be planned on the basis of having sufficient information to allow prior assessment of the possible impact (BONNER 1994). Annex I to the Protocol deals with Environmental impact assessment. It is based on Recommendation XIV-2 but has a much broader content. Annex II is formed on the basis of the Agreed Measures and deals with conservation of Antarctic fauna and flora. Annex III, which builds on the above-mentioned Recommendation XV-3, involves waste disposal and waste management. And Annex IV deals with issues regarding marine pollution (MACHOWSKI 1992, BONNER 1994).

Up to now, as BONNER (1990) pointed out, „...the previsions of a legislative basis for conservation has gone further in the Antarctic than for any other comparable area in the world." However, of first importance is how to make the conservation measures become effective on the ground. An effective implementation of the Protocol needs not only to get support from parties at the governmental levels, but to ensure that all who visit and work in the Antarctic put it into practice. The Antarctic will remain in its natural and clean state only when much effort is put into environmental conservation.

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