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A GIS FOR THE ANTARCTIC SPECIALLY MANAGED AREA OF ADMIRALTY BAY, KING GEORGE ISLAND, ANTARCTICA

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ABSTRACT A GIS is proposed as a tool for the managing plan for the Antarctic specially managed area (ASMA) in Admiralty Bay. The ASMA comprises the area considered to be within the glacial drainage basin of the bay. Furthermore, it includes part of SSSI No. 8 adjacent to the area but outside of the glacial drainage basin. Three stations and six refuges are located in the area. Using a SPOT satellite image map, the limits of the ASMA are marked and its area is re-calculated. It consists of 362 km^2, including 186 km^2 island ice field and small cirque glaciers and 32 km^2 ice-free field. The rest comprises water of the bay and a small adjacent area (8 km^2) of the Bransfield Strait.

The ASMA-GIS will consists of 12 data layers ranging from the physiographic settings to the biological and administrative features. All data will be implemented into Arc/Info GIS according to the cartographic guidelines of the SCAR WG-GGI. First, five plans of information will be realised using a topographic database compiled from various sources and data from the revised bathymetric chart published by the Brazilian Navy Hydrographic Survey and also including: 1) Limits of the ASMA and protected areas; 2) Glaciological features (e. g. drainage basin limits) and 3) Human presence (e. g. stations and historical sites). These basic GIS layers will be operational in early 2001. Then, additional data on the remaining layers (e. g. hydrology, geology and geomorphology) will be included from published sources.

The ASMA-GIS will form an important database for environmental monitoring and studies surveying temporal changes of features such as glacier front positions or bird breading sites.

1 Introduction

King George Island's (KGI) ecosystems have been subjected to various types of exploitation and object of several scientific expeditions, since it was discovered just after the first sighting of Antarctic land by William Smith in 1819. KGI was named after the British king of that time. Nowadays it is also one of the main Antarctic touristic attractions. Therefore, a brief overview on the historic human activities on Admiralty Bay is given before discussing the Antarctic Treaty initiatives to protect part of this area. This information forms the background setting for the main objective of this paper — the implementation of a GIS for the Antarctic specially managed area (ASMA) of Admiralty Bay. We present the basic concepts and the initial data layers of the ASMA-GIS.

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2 A brief history of human activity in Admiralty Bay

Admiralty Bay has been visited and used as a well-protected anchorage since the early stages of Antarctic sealing during 1820s. After the demise of this economic activity, due to over-exploitation, sealers returned briefly in the 1840s and again in the 1870s. The bay was also visited by some European exploratory expeditions in the 19th century. Notwithstanding, the period of most intense activities began when the floating whaling factory Admiralen arrived there in January 1906, accompanied by two whale-catchers. This marks the beginning of whaling in the South Shetlands and though the factory ships were dislocated in 1907 to other islands in the region, Admiralty Bay remained a major harbour for whalers until 1931 (Headland & Keage, 1985). Today, remains of the whaling industry (whalebones, wooden parts) are still found widely spread in the area, testifying about the intensity of the exploitation. A large amount of place names were given during this period as, for example, Telefon Rocks, near the entrance of the bay, marks the place where the factory ship Telefon sank in 1908.

Several exploratory expeditions visited the area before the Second World War. Jean-Baptiste Charcot's expedition (1908 ~ 1910), sailing in the Pourquoi Pass, deserves attention as it produced the first detailed chart of the bay.

Modern activities began in 1947 when the Falkland Islands Dependencies Survey (FIDS) built a small hut in the eastern Keller Peninsula which is identified by an arrow in Fig. 1. This was the origin of the first scientific station on the island, called Base *G*. In the following years, the base was enlarged to several buildings and it was operated until January 1961. In the summer of 1947 ~ 1948, a small Argentine hut was built adjacent to Base *G* and occupied for just one season. In order to keep the area clean, Brazil removed all these old and abandoned buildings on Keller Peninsula in the late 1990s.

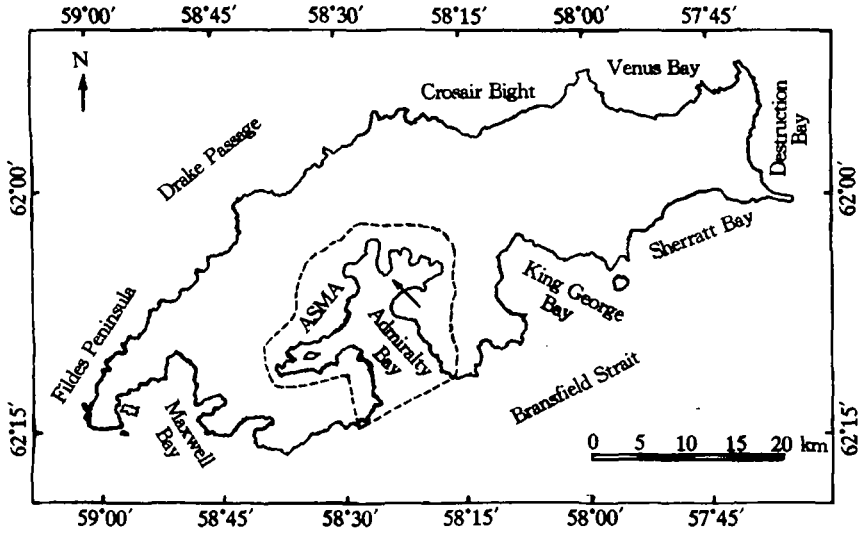

Fig. 1 Limits of the Antarctic specially managed area (ASMA) of Admiralty Bay

The second wave of building scientific stations began when Poland established Henryk Arctowski Station near Point Thomas in February 1977. Today huts, storage rooms and oil tanks spread over an area of 100 000 m^2. The Brazilian Station Comandante Ferraz on Keller Peninsula was constructed beside the old Base G in February 1984. Several refuges, scientific modules and a large heliport were built on this peninsula. By the same time, an American hut (Pietr J. Lenie) had been established, for ornithological research on the western shore of the bay, near Arctowski station. Moreover, in January 1988, a small refuge called the "República do Ecuador" was installed at Hennnequin Point. Finally, Peru set up Machu Picchu station on Crepin Point (Mackellar Inlet) in 1989.

At present, human population in the bay reaches a summer peak of about 80 persons. In winter, only

the Brazilian and Polish stations remain occupied and personnel are reduced to about 30.

Since 1970s, Admiralty Bay has become one of the main touristic sites of Antarctic due to an impressive natural landscape, good anchorage, numerous wildlife and relatively mild climate. According to the International Association of Antarctic Tour Operators-IAATO (1999), 1 707 tourists disembarked in its shores in the summer of 1997～1998.

3 Protected areas

Two sites are currently protected by the Antarctic Treaty in the area of the Admiralty Bay: 1) the Site of Special Scientific Interest No. 8 (SSSI No. 8) on the western shore of the bay (seaward of a line joining Telefon Rocks to Jardine Peak, and south of a line bearing approximately 68° to the shoreline[1], and 2) the Historic Monument No. 51 (62°13′ S, 58°28′ W), near Arctowski station. It was formed by the grave (and cross) of Wlodzimierz Puchalski, artists and documentary producer, died whilst working in that station.

The SSSI No. 8 was designated because the area supports an exceptional assemblage of Antarctic birds (several colonies of penguins) and mammals (seals and elephant seals). One of the main objectives of this SSSI is to protect long term research, carried out mainly by American and Polish scientists on Pietr Lenie Hut (located inside the SSSI). The SSSI No. 8 is to have been revised by the end of the year 2000.

4 The Antarctic specially managed area (ASMA) of Admiralty Bay

In the early 1990s, it was noticed by the two main national Antarctic programmes (Brazil and Poland) operating in Admiralty Bay that the increasing number of human activities would cause considerable impact on the ecosystems in the area.

Taking into consideration the increasing activities in the area and the articles 2 and 4～6 of Annex V of the Protocol to the Antarctic Treaty on Environmental Protection (i. e. Protocol of Madrid signed in 1991; ATCPs, 1993), Brazil and Poland jointly, and in co-ordination with Ecuador and Peru, submitted the first proposal for an Antarctic specially managed area to the Antarctic Treaty Consultative Parties (ATCPs). In 1996, "under the grounds of outstanding environmental, scientific, scenic and historic value, and the number of national Antarctic programmes and tourists parties operating in close proximity to one another" the proposal was adopted in Utrecht, Netherlands (ATCPs, 1996), and a managed plan was voluntarily adopted by the contracting countries.

The ASMA boundaries shown in Fig. 1 were the limits of the glacial drainage basins flowing into the bay. It also comprises part of the present SSSI No. 8 that is adjacent to this region but outside the drainage basin. Therefore, "the area is bounded by a line extending from Telefon Point (62°14′ S, 58°28′ W) in the south to the Tower (62°13′ S, 58°29′ W), then towards Jardine Peak (62°10′ S, 58°30′ W) intersecting the ice divide of the Warszawa Ice Field, thence following this divide to the west of Ezcurra Inlet (62°10′ S, 58°33′ W), north eastwards to enclose Mackellar (62°05′ S, 58°27′ W) and Martel Inlets (62°05′ S, 58°22′ W), and then southwards through Ternyck Needle (62°05′ S, 58°16′ W) to Syrezol Rocks (62°12′ S, 58°17′ W) on the eastern shore of Admiralty Bay. The waters of Admiralty Bay, and a small part of Bransfield Strait north of a straight line between Syrezol Rocks and Telefon Point, are also included in the ASMA[1].

5 A GIS as a base for the proposed ASMA management plan

The multi-use of the bay, the administration of conflicts of use, the monitoring of environmental changes and the human impact on biological and physiographic features demanded a management plan as developed for the ASMA. However, such an administrative guideline requires the design of a comprehensive standardised database. A GIS with several data layers for the different features will provide this information for the area and enable an easy and regular update, access and cartographic input. Till now, a large variety of data sets are avail-

able, ranging from detailed topographic measurements, glaciological surveys and bathymetric data. However, spatially distributed information on fauna and flora as about vegetation cover and bird colonies are scarce. To keep the GIS compatible to other systems and to follow the standardised guidelines by the SCAR WG-GGI, all data will be integrated into Arc/Info system using the suggestion of Sievers & Bennat (1989) for map projection (Lambert conformal conic projection) and WGS84 as map datum. The accuracy of the input data will allow an output to a scale between 1:25 000 and 1:50 000.

6 The ASMA GIS data layers

In the GIS, all relevant ecological features have to be included. Consequently, a variety of data layers have to be designed including

1) surface topography,
2) bathymetry,
3) ASMA and SSSI limits,
4) human presence (buildings, historic monuments),
5) glaciological features (including drainage basins limits, multi-temporal ice fronts positions, firn line altitude, glacier velocity vectors, etc.),
6) place names,
7) ice bed elevation,
8) hydrology (rivers, lakes),
9) geomorphological features,
10) geology,
11) vegetation fields,
12) fauna (e. g. penguin colonies, sea elephant beaches).

First the layers 1 to 5, which contain the physiographic settings and glaciological features, will be included in the GIS and be operational by early 2001. Then, in several further steps, the other data layers will be filled according to the data availability. All data layers will contain information on data accuracy, data origin and contact persons. The next paragraphs describe these layers and Table 1 lists the main data sources.

The topographic layer is based on the recent work by Braun, *et al*. that integrates information from the ADD[2] and digitised contour lines from a Polish map of the bay[3] with differential GPS surveys carried out over the KGI ice field in the summers of 1997～1998 and 1999～2000. Further details on the database compilation can be found in the paper by Braun, *et al*. (this volume). Reference points for satellite geo-coding were collected on marked coastal features by a group from the Laboratório de Pesquisas Antárticas e Glaciológicas (LAPAG), Universidade Federal do Rio Grande do Sul (Brazil), and the Institut für Physische Geographie (IPG), Universität Freiburg (Germany). Positioning was done using a single GPS collecting averages of 1 500 points. This provides ground control points to a precision of about 15 m.

The bathymetric layers will be digitised from a Brazilian Navy Hydrographic chart[4] that integrates, at a scale of 1:40 000, the data obtained by several Brazilian surveys, mainly for the central part of the bay.

These two layers are the basic information of the GIS and are essential for the proper delimitation of the ASMA. It is important to notice that according to the Annex V of the Protocol on Environmental Protection to the Antarctic Treaty, proposed management plans for protected areas require, inter alia, maps and photographs that "show clearly the boundary of the area in relation to surrounding features and key features within the area"[5]. In case of Admiralty Bay ASMA, only an imprecise description of its borders, based on the British Antarctic Survey map (1968) at scale 1:200 000, existed prior to the work developed by Braun, *et al*. The topographic layer, associated to a satellite image map, gave the new limits of the ASMA, remarked as defined in the XX ATCM (Fig. 1 and 2). The total area of the ASMA was reduced to 362 km^2 (against 370 km^2) of which 51% are covered by the KGI ice field, 38% are waters of Admiralty Bay and 2% of the adjacent Bransfield Strait. All buildings, terrestrial flora, fauna, and visits of tourists develop over the remaining 32 km^2 (9%) ice free area. By the way, in Fig. 2, the numbers 1～9 refer to the stations and refuges established by several countries. They are respectively:

Table 1 Maps, charts, aerial photographs, satellite images and other data sets to be integrated in the Admiralty Bay ASMA GIS

Title	Date	Scale/ Resolution	Estimated vertical accuracy	Source	Projection and geoid model	Input data
Admiralty Bay	1990	1:65 000 approx	30 m	Nakladem Instytutu Ekologii Polskiej Akademii Nauk, Poland	Gauß-Krüger-coordinate system and geographic coordinates, Krassowski geoid, 1942	Ground survey by theodolit and aerial photography from 1978~1979
Antarctic Digital Database, Ver. 3.0	2000		100 m	BAS homepage	Stereographic projection	BAS 1968 maps 1:200 000
Baía do Almirantado	1992	1:40 000		Diretoria de Hidrografia e Navegacão (DHN), Rio de Janeiro, Brazil	Mercator projection WGS84	Bathymetry (DHN surveys & Admiralty charts)
DGPS height points	1997~1998	1 m	2 m	Institut für Geophysik, Universität Münster; Institut für Physische Geographie, Universitüt Freiburg, Germany	UTM, WGS84	Mobile DGPS survey in 1997~1998 by a Brazilian-German Expedition
GPS survey points	2000	15 m		Institut für Physische Geographie, Universität Freiburg, Germany; Laboratório de Pesquisas Antárticas e Glaciológicas, Brazil	UTM, WGS84	GPS survey in 1999~2000 by a Brazilian-German Expedition (coastline, ice front positions, buildings, historical monuments)
SPOT-1 XS Satellite Image	19 Feb. 1988	20 m		SPOTIMAGE Frame No. 725~478	Georeferenced to UTM, WGS 84	Coastline and Glaciological features
SPOT-3 XS Satellite Image	26 Nov. 1994	20 m		SPOTIMAGE Frame No. 725~478	Georeferenced to UTM, WGS84	Coastline and Glaciological features
SPOT-3 XS Satellite Image	29 Mar. 1995	20 m		SPOTIMAGE Frame No. 725~478	Georeferenced to UTM, WGS84	Coastline and Glaciological features
SPOT-3 XS Satellite Image	29 Mar. 1995	20 m		SPOTIMAGE Frame No. 725~477	Georeferenced to UTM, WGS84	Coastline and Glaciological features
SPOT-4 XS Satellite Image	23 Feb. 2000	20 m		SPOTIMAGE Frame No. 725~478	Georeferenced to UTM, WGS84	Coastline and Glaciological features
Satellite Image Corona mission	29 Aug. 1962 to Oct. 1963			USA		Coastline
Aerial Photography	1956	20 m 1:27 000		FIDASE (UK)		Ice front positions
Aerial Photography	1976	1:11 000		Royal Navy (UK)		Ice front positions
Radio echo-sounding survey (ice thickness and bedrock altitude)	1997~1998	1 m		Institut für Geophysik, Universität Münster; Institut für Physische Geographie, Universität Freiburg, Germany	UTM, WGS84	Overland RES survey in 1997~1998 by a Brazilian-German Expedition
Radio echo-sounding survey (ice thickness and bedrock altitude)	1995~1996	200 m	10 m	Institute of Geography, Russian Academy of Sciences		Overland RES survey in 1996~1997 by a Brazilian-Russian group
Radio echo-sounding survey (ice thickness and bedrock altitude)	1996~1997	200 m	10 m	Institute of Geography, Russian Academy of Sciences		Overland RES survey in 1998~1999

1 – Comandante Ferraz Station (Brazil) and emergency refuge,
2 – Scientific module (Brazil),
3 – Refuge (Brazil),
4 – Machu Picchu Station (Peru),
5 – Refuge Republica do Ecuador (Ecuador),
6 – Henryk Arctowski Station (Poland),
7 – Pietr J. Lenie hut (USA),
8 – Refuge (Poland),
9 – Refuge (Poland).

Satellite imagery and aerial photographs give precise information on the coastline at present and its changes during the past 45 years. The coastline was brought up to date using information from a SPOT XS image with a resolution of 20 m that was obtained in February 2000. Historical data were obtained from other SPOT images (from 1988 to 1995), two aerial photographic surveys by the FIDASE (1956) and the Royal Navy (1975). Presently, other imagery such as a Landat MSS from February 1979 and recently declassified Corona Mission photographs (1963) are being evaluated

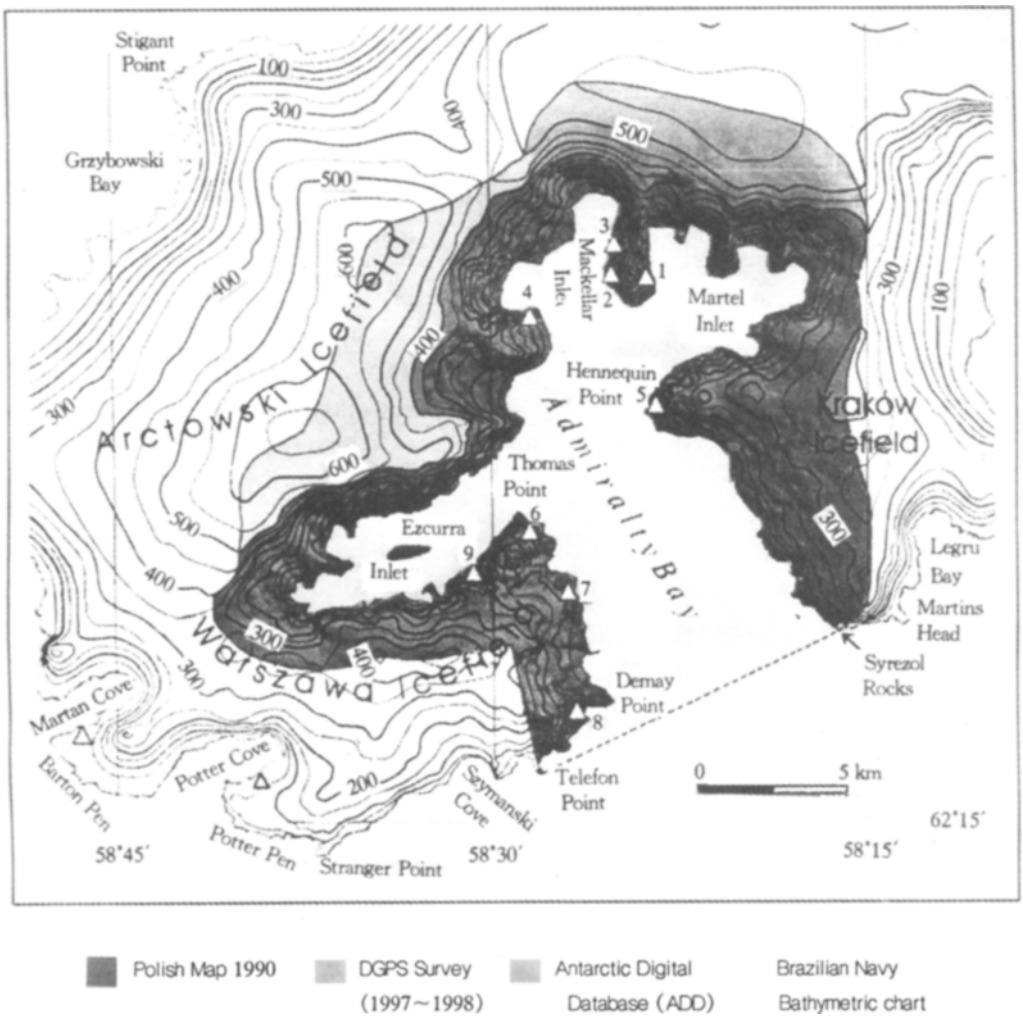

Fig. 2 Data sets used to define the topographic and bathymetric layers in the Admiralty Bay ASMA GIS

to check if they may be used to derive past ice front positions, albeit in smaller scale of resolution.

It is important to notice that in the last three years several authors detected relatively fast changes in the coastline. Ice front retreat is generalised in the ASMA area (Simões, *et al.*, 1999). Braun, Rau & Simões, in this volume, give details about the work carried out to calculate the glacier area lost since 1956 (about 11.8 km^2) and provide information on the data the coastline layer is derived from.

The glaciological layer contains information such as drainage basin limits, ice thickness, snow line altitude, glacier velocity vectors, etc. It is derived from several papers and dissertations[6~8]. Single ice front positions of eight glaciers were obtained by the Brazilian-German GPS in February 2000. Ice thickness measurements inside the ASMA area have been obtained by three radio echo-soundings surveys carried out by Russian, Russian-Brazilian and German-Brazilian expeditions[7~10].

The human presence layer is a compilation of information contained in articles and the map published by the Polish Institute of Ecology[3]. The recent Brazilian-German GPS survey cited above improved the spatial reference of features such as stations and refuges, historic monuments, heliports, footpaths and limits of protected areas.

A place names layer is essential considering that multi-naming is frequent due to the number of nations operating in Admiralty Bay and its long history of occupation. The proposed layer will follow the "one place name per feature" rule proposed by Sievers & Thomson (1995), giving priority to the first recorded name.

In February 2000, a test was carried out by a Brazilian-German GIS survey on Keller Peninsula to locate the main mosses fields and bird colonies

(Skuas, Southern gull, Larus dominicanus) near Ferraz Station. During the next three years, biologists will be invited to identify areas of main concern, for example, the penguins colonies inside the SSSI No. 8. These will be delimited and included in the fauna layer. Similar work will be done for the vegetation layer (mainly mosses).

Bedrock elevation will be constructed from several radio echo-sounding surveys carried out since the year of 1995[7,8,10], mainly in the west area of Mackellar Inlet. Therefore, the area coverage is limited. Finally, the geological, geomorphological and hydrological layers will be derived from information published in papers and geological maps[11] that summarises the knowledge for KGI.

7 Conclusions

The general structure and the need of the Admiralty Bay ASMA GIS were outlined. The cartographic base follows the guidelines of the SCAR WG-GGI and a high compatibility to the planed KGI-GIS is intended. In a first step, five data layers comprising surface elevation, bathymetry, limits of specially protected sites, human presence and glaciological features will be implemented. Further, additional layers as on flora and fauna will be included according to data availability. The GIS will form an important database for environmental monitoring and studies surveying temporal and areal changes of features such as glacier front positions or bird breading sites. Consequently, the collection of new ecological data should be combined with a proper geographic positioning, e. g. by handheld GPS. An easier access to the existing data sets will help considerably the administration of scientific and logistic activities in the ASMA.

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