POLISH POLAR RESEARCH
vol. 34, no. 1, pp. 55–66, 2013 doi: 10.2478/popore-2013-0005

Alien invertebrates transported accidentally to the Polish Antarctic Station in cargo and on fresh foods

Katarzyna J. CHWEDORZEWSKA[1], Małgorzata KORCZAK-ABSHIRE[1], Maria OLECH[1,2], Maria LITYŃSKA-ZAJĄC[3] and Anna AUGUSTYNIUK-KRAM[4]

[1]*Instytut Biochemii i Biofizyki PAN, Zakład Biologii Antarktyki, ul. Pawińskiego 5a, 02-106 Warszawa, Poland* *<kchwedorzewska@go2.pl> <korczak@gmail.com>*

[2] *Uniwersytet Jagielloński, Instytut Botaniki, ul. Kopernika 27, 31-501 Kraków* *<Maria.Olech@ib.uj.edu.pl>*

[3] *Instytut Archeologii i Etnologii PAN, oddział w Krakowie, ul. Sławkowska 17, 31-016 Kraków* *<marialitynska@gazeta.pl>*

[4]*Instytut Ekologii i Bioetyki, Uniwersytet Kardynała Stefana Wyszyńskiego w Warszawie, ul. Dewajtis 5, 01-815 Warszawa and Polska Akademia Nauk, Centrum Badań Ekologicznych, ul. M. Konopnickiej 1, Dziekanów Leśny, 05-092 Łomianki* *<aaugustyniuk-kram@cbe-pan.pl>*

Abstract: During three austral summer seasons cargo, expeditioner clothes and equipment of the Polish Antarctic Expedition were examined for the presence of alien propagules. Detailed inspections were undertaken at the station buildings, searching for any invertebrates. During each austral summer fresh fruits and vegetables were also inspected. A total of 359 invertebrates and their remains were found in cargo transported to *Arctowski* Station, or caught in the station's facilities. The majority of samples were classified as cultivation pests (26%), food pests (43%), wood-destroying pests (4%), domestic insects and arachnids (15%). Through supply of the research station a wide range of alien organisms can be accidentally transported and ultimately introduced to the Antarctic. This study has clearly demonstrated that almost all cargo items can be a potential vector for alien organisms. Species from a broad range of biological groups can be transported to the Antarctic and remain in a viable state.

Key words: Antarctic, alien species, human impact, invertebrates.

Introduction

Oceanic and atmospheric circulation patterns around the Antarctic significantly restrict the transfer of organisms into and out of this region, making this continent the most isolated on the planet (Clarke *et al.* 2005; Chown and Convey 2007). Presently, some regions of Antarctica are facing very rapid climate change. This affects major environmental variables of considerable biological significance (Convey 2006, Convey *et al.* 2009). Despite the geographical and historical isolation of this remote region and the harsh environmental conditions, introduction of exogenous organisms have taken place in the Antarctic, some with significant impact on native biota (Pugh 1994; Lewis-Smith 1996; Olech 1996; Greenslade 2002; Chwedorzewska 2008; Olech and Chwedorzewska 2011; Chwedorzewska and Bednarek 2012; Cuba-Diaz *et al.* 2012; Molina-Montenegro 2012).

Some species may potentially overcome natural colonisation barriers of the Antarctic, those transported in a natural manner like anemochory (Lewis Smith 1984, 1991, 1993; Bargagli *et al.* 1996; Marshall 1996), hydrochory (Coulson *et al.* 2002), zoochory (Barns *et al.* 2004) or marine debris (Barns and Fraser 2003; Barns *et al.* 2004; Lewis *et al.* 2005), but evidence of that kind of transportation are rather limited (Hughes *et al.* 2006). In recent decades the transport distribution barrier around Antarctica has been circumvented by a rapid increase in human activity in this region (Lee and Chown 2009a, b; Hughes *et al.* 2010b). Globalization and increasing human movements are particularly apparent in the Antarctic. During the early 21st century the number of visitors and the size of human influence have increased dramatically (Lee 2008; Chwedorzewska and Korczak 2010). In spite of the significant number of tourist visits (Chen and Blume 1995; Stonehouse 1999; Chwedorzewska 2009; see www.iaato.com) the main introduction routes seems to be associated with the supply of polar stations by cargo and personnel (Lee and Chown 2009b; Chwedorzewska and Korczak 2010; Chown *et al.* 2012; Lityńska *et al.* 2012). Probable vectors may include packing materials, vehicles, imported fresh foodstuffs, adhered soil, scientific equipment, building materials, clothing and footwear (*e.g.* Whinam *et al.* 2005; Lee 2008; Lee and Chown 2009 a,b; Osyczka 2010; Osyczka *et al.* 2012; Tsujimoto and Imura 2012).

Most of the research stations are located at the ice-free coastal zones, sheltered from winds and with access to liquid fresh water. This topography often represents a favourable microclimate (Poland *et al.* 2003; Hull and Bergstom 2006; Lamers 2009; Hughes *et al.* 2011). Due to the interaction of a favourable microclimate, amelioration of environmental condition and expanding human footprint, the likelihood of the establishment of alien organisms have increased. Numerous observations exist of the unintentional importation of alien plants and invertebrates to the sub-Antarctic islands through human activity (*e.g.* Frenot *et al.* 2005; Whinam *et al.* 2005). These islands are the first stepping stones for new colonizers; possible introduction could be supported by climate amelioration along the Scotia Arc archipelagos and Antarctic Peninsula (Chown *et al.* 2012).

The goal of this investigation was to quantify alien invertebrate propagule pressure at the Polish Antarctic Station and assess their potential impact on the Antarctic terrestrial ecosystem.

Materials and methods

During three austral summer seasons (2007/2008, 2008/2009, 2009/2010) cargo, expeditioner (scientists and support personnel) clothing and equipment of the Antarctic Expedition to the Polish Antarctic Station *H. Arctowski* (King George Island, South Shetlands Islands, 62°09’S, 58°28’W) were examined for the presence of alien organisms. A majority of the expeditions cargo was taken from Gdynia (Poland). Some fresh products, mainly fruits and vegetables, were taken from Mar del Plata (Argentina).

Inspections of cargo and containers were conducted in the Antarctic station warehouse. The cargo included a few types of crates: aluminium containers for personal items, large plastic containers, wooden shipping pallets (with cargo strapped on the surface) and wooden chests. Bulk cargo included: containers, machinery, gas bottles, liquefied petroleum barrels, strapped bundles of timber and all other station resupply items in bubble wrap (Table 1). All the items were swept and all contaminates were tagged and placed in a paper bags. The insides of aluminium and plastic containers, wooden chests were vacuumed to individual dust bags and a new nylon stacking filter was put on the vacuum hose each time to catch any invertebrates or propagules.

During the three seasons all personal field clothing, gear and equipment of the expeditioners (on average 20 persons per season; in total 78) were vacuumed, each to a separate dust bag. A new nylon stocking filter was put on the vacuum cleaner hose to collect the larger contaminants. Each sample was tagged and preserved (were frozen in -20°C) for transportation to Poland for future analysis.

A detailed inspection searching for spiders and winged insects was undertaken regularly at the station buildings, mainly at food warehouses and living quarters.

Table 1

Average number of cargo items examined per expedition

Type of container	Number of containers examined	Origin
Metal container (0.3 m^3)	20	Poland
Plastic container (1.0 m^3)	5	Poland
Wooden shipping pallet with cargo	20	Poland
Gas bottle (capacity 33 kg)	15	Poland
Barrel (capacity 200 l)	25	Poland
Vehicle equipment	4	Poland
Scientific equipment	10	Poland
Crate with fruits and vegetables (capacity 20 kg, 0.1 m^3)	40	Poland/Argentina
Sack of potatoes (capacity 30 kg)	50	Poland
Sack of parsley, carrot or root celery (capacity 20 kg)	10	Poland
20 Ft reefer container	1	Poland

During the austral summer fresh fruits and vegetables were inspected, at least two times. All invertebrates or their remains were collected, placed in separate zip lock bags, marked and frozen for future taxonomic examination in Poland. Materials were identified by authors and doubts were consulted with specialists from Warsaw University of Life Sciences-SGGW.

Results

Cargo transit time from Gdynia to the *Arctowski* Station by ship typically takes 40 to 44 days; from Mar del Plata to the station 6 to 10 days (depending on the weather). All cargo destined to the Antarctic station was mainly transported from Poland, but some fresh products, like about 20 crates with fresh fruits and vegetables and about 150 kg of frozen beef are taken from Mar del Plata every year.

The average number of cargo items inspected per season was 200 (Table 1). During three summer seasons a total of 359 invertebrates and their remains were found in the cargo transported to *Arctowski* or caught in the station facilities. Only 25% of them were dead. A majority of them could be classified as: food pests (43%), cultivation pests (26%), wood-destroying pests (4%) and domestic insects and arachnids (15%) (Table 2). On personal field clothing, gear and equipment of expeditioners no invertebrates were found.

Table 2

Introduction of invertebrates to *Arctowski* Station with resupply by three expeditions.

Pest groups	Higher taxonomy	Latin name	Number of individuals (alive/**dead**)	Location	Additional informations
Food pests	Drosophilidae	*Drosophila melanogaster* Meigen, 1830	46 (46/**0**)	vegetable warehouse	fresh fruit and vegetables
	Curculionidae	*Sitophilus granarius* (Linnaeus, 1758)	39 (25/**14**)	dry warehouse	cereal products
	Tenebrionidae	*Tenebrio molitor* (Linnaeus,1758)	15 (12/**3**)	dry warehouse	cereal products
	Pyralidae	*Ephestia kuehniella* Zeller, 1879	32 (20/**12**)	dry warehouse	cereal products
	Acaridae	*Acarus siro* (Linnaeus,1758)	21 (21/**0**)	dry warehouse	cereal products
Cultivation pests	Anthomyiidae	*Delia platura* (Meigen, 1804)	2 (2/**0**)	vegetable warehouse	leafy vegetables
	Anthomyiidae	*Delia radicum* (Linnaeus, 1758)	8 (6/**2**)	vegetable warehouse	leafy vegetables
	Sciaridae	*Ctenosciara hyalipennis* Meigen, 1804	16 (16/**0**)	vegetable warehouse	fresh fruit and vegetables
	Aphidoidea	non det.	33 (33/**0**)	vegetable warehouse	leafy vegetables
	Curculionidae	*Ceutorrhynchus* spp. Latreille, 1802	3 (0/**3**)	vegetable warehouse	leafy vegetables

Table 2 – *continued*.

Pest groups	Higher taxonomy	Latin name	Number of individuals (alive/**dead**)	Location	Additional informations
Cultivation pests	Hemiptera	non det.	5 (3/**2**)	vegetable warehouse	root and tuber vegetables
	Oniscidae	*Oniscus asellus* Linnaeus, 1758	13 (10/**3**)	vegetable warehouse	root and tuber vegetables
	Agriolimacidae	*Deroceras laeve* (O.F. Müller, 1774)	8 (8/**0**)	vegetable warehouse	leafy vegetables
	Agriolimacidae	*Deroceras agreste* (Linnaeus, 1758)	3 (3/**0**)	vegetable warehouse	leafy vegetables
	Helicidae	*Cepaea hortensis* (O.F. Müller, 1774)	2 (1/**1**)	vegetable warehouse	leafy vegetables
	Helicidae	*Cepaea vindobonensis* (C. Pfeiffer, 1828)	1 (1/**0**)	vegetable warehouse	leafy vegetables
Wood-destroying pests	Scolytidae	*Ips typographus* Linnaeus, 1758	6 (2/**4**)	wooden pallets	bark
	Anobiidae	*Anobium punctatum* (De Geer, 1774)	7 (0/**7**)	wooden pallets	bark
Domestic insects and arachnids	Formicidae	*Monomorium pharaonis* (Linnaeus, 1758)	9 (9/**0**)	living quarters	
	Tineidae	*Tineola bisselliella* (Hummel, 1823)	14 (14/**0**)	living quarters	
	Muscidae	*Musca domestica* Linnaeus, 1758	16 (4/**12**)	living quarters and inside the containers	
	Agelenidae	*Tegenaria* spp.	8 (3/**5**)	living quarters and inside the containers	
	Agelenidae	*Tegenaria domestica* (Clerck, 1757)	1 (1/**0**)	living quarters	
	Agelenidae	*Tegenaria atrica* C.L. Koch, 1843	3 (1/**2**)	living quarters and inside the containers	
	Araneidae	*Araneus diadematus* Clerck, 1758	1 (1/**0**)	living quarters	
Others	Vespidae	*Vespula vulgaris* (Linnaeus, 1758)	2 (0/**2**)	inside containers	cargo
	Apidae	*Apis mellifera* Linnaeus, 1758	1 (0/**1**)	inside containers	cargo
	Culicidae	*Culex* spp.	21 (21/**0**)	vegetable warehouse	
	Scarabaeidae	*Melolontha melolontha* (Linnaeus, 1758)	1 (0/**1**)	inside containers	cargo
	Coccinellidae	*Coccinella septempunctata* Linnaeus, 1758	8 (0/**8**)	inside containers	cargo
	Coccinellidae	*Anatis ocellata* (Linnaeus, 1758)	4 (0/**4**)	inside containers	cargo
	Nymphalidae	*Inachis io* (Linnaeus, 1758)	4 (0/**4**)	inside containers	cargo
Total			359 (271/**90**)		

Inside the containers (aluminium, plastic and wooden chests) only dead invertebrates or their remains were found (*e.g.* flies, bees, wasps, butterflies).

Inspections of fresh products (especially fruits and vegetables) revealed a high number of living invertebrates, particularly in leafy vegetables like red and white cabbage, lettuce or in fresh herbs like basil and coriander (*e.g.* Aphidoidea, snails). Root or tuber vegetables, such as potatoes, carrots, parsley, celery, leeks and beets, were often contaminated with soil. In this soil and in the wooden crates containing them there were found some invertebrates like *Oniscus asellus* or some species of Hemiptera. A majority of those organisms could be classified as cultivation pests (Table 2). Fruits and vegetables like apples, oranges, pears, avocados, capsicums, tomatoes, garlic, onions, were almost invertebrates free.

Living insects and acarids were also found in dry infested cereal products (*e.g.* *Sitophilus granarius*, *Ephestia kuehniella, Tenebrio molitor*, *Acarus siro*) which were classified as food pests.

A diverse groups of invertebrates, like flies and spiders which commonly occur in human domestic environment, were found in living quarters, warehouses and even inside vehicle cabins. Inspection of station facilities including cool storage (+4°C, mainly vegetables and fruits), dry storage and the kitchen allowed us to find some winged insects feeding on spoiled vegetables and fruits. Furthermore, populations of *Drosophila melanogaster* and *Ctenosciara hyalipennis* were found in the vegetable warehouse and were hard to exterminate. Each year several mosquitoes (*Culex* spp.) were also caught in this facility (Table 2).

Discussion

Through cargo and expeditioners a wide range of alien organisms or their propagules can be transported unintentionally and introduced ultimately to the Antarctic from distinct habitats all over Earth (Whinman *et al.* 2005; Hughes *et al.* 2010b). Ships and planes can transport alien species between locations relatively rapidly. This helps organisms retain viability during transit (Hughes *et al.* 2010a). More than one hundred year-round or summer only stations, refuges and field camps are re-supplied annually or several times each year (Chwedorzewska 2009; Hughes *et al.* 2010b, Hughes and Convey 2010, 2012). *Arctowski* Station main cargo is usually supplied once a year, but a couple of times during the summer season they are re-supplied by ships with small amounts of fresh products from South America. During transportation from Poland (six weeks) and Argentina (less than two weeks) to the Polish Antarctic Station, fresh products were kept at 4°C to prolong their longevity. This condition may also promote survival of a wide spectrum of associated organisms. The rest of the cargo (in average 30 tons per year), excluding frozen items, were kept in the ships hold, where conditions may also allow the survive of many species (Hughes *et al.* 2010b). This study has clearly demon-

Table 3

Monthly and annual averages of air temperature and atmospheric precipitation totals in 2006 on *Arctowski* Station, King George Island (original data) and Gdynia (Poland) according to Statistical Yearbook of Gdynia City (http://www.gdynia.pl/g2/2012_05/53657_fileot.pdf.)

Air temperature [°C]													
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Arctowski	3.7	3.2	3.3	-0.3	-0.2	-3.7	-3.8	-8.6	-4.2	0.2	0.5	1.9	-0.7
Gdynia	-3.9	-0.7	0.0	6.3	12.2	16.1	21.5	18.2	16.9	12.3	7.4	6.3	9.5
Atmospheric precipitation totals [mm]													
Arctowski	22.5	55.0	115.9	125.2	84.0	14.8	22.1	10.4	35.6	44.1	23.9	56.9	610.4
Gdynia	6.7	16.9	13.4	61.2	44.6	68.0	16.1	144.7	29.9	31.7	54.3	30.7	518.2

strated that a lot of cargo items can act as potential vectors for alien organisms. Additionally species from a broad range of biological groups can be transported into Antarctic with expeditions (Table 2).

The range of the organisms introduced to the Polish Antarctic Station by expeditions was very wide and diverse, although some of them didn't survive transportation (25%). Remains of social invertebrate species like wasps or honey bee, represented by sterile worker females were found. Some species like for example *e.g. Melolontha melolontha,* as well as two species of Coccinellidae are not able to survive transportation, because their imago lives too short. Numerous invertebrates were found alive on fresh products, but organisms associated with fruits and vegetables mainly belonged to cultivation pests strongly specialized. These organisms are unlikely to survive outside in the Antarctic conditions, since they are not able to find their feeding niche (*e.g. Delia radicum* feeds on crop and weed plants from Brassicaceae); moreover they are temperate or even tropical organisms (Table 2). Also wood-destroying pests found in wood, wooden crates and pallets are not able to survive outdoors without access to fresh wood and bark. Group of domestic invertebrates was represented by four species of spiders. Even surviving polar climate they would not be able to find a proper prey in natural Antarctic condition. Also, synanthropic species, like ants (*Monomorium pharaonis*) originating from Africa or common clothes moth (*Tineola bisselliella*) cannot create a threat. Better adopted to polar condition seems to be *Culex* spp. (mosquitoes) which are numerous in the Arctic and may have the ecophysiological features required for survival in Antarctic environment, if they will be able to feed on local animals gathering along the shore during summer season. In Arctic mosquitoes occur mainly in windless habitat, so it is presumed that very strong wind blowing in South Shetlands throughout the most of a year protects this region from their establishment.

Some alien species as occasionally found individuals of domestic insects and spiders (Table 2) may survive synanthropically for prolonged periods (Hughes *et al.* 2005) and some of them would be able to establish reproducing populations at station facilities (Hughes *et al.* 2005). This study reports the presence of populations of quickly reproducing species like *Drosophila melanogaster* or *Ctenosciara hyalipennis* in vegetable storage and *Ephestia kuehniella* or *Acarus siro* in dry storage. All these species do not possess the ecophysiological or adaptations life-history features required for survival in the Antarctic environment. Their prolonged presence however highlights the need of regular and strict controls of the station facilities every expedition year. Mentioned above alien organisms were relatively easily eradicated by cleaning the storage and incinerating the remains of fresh products along with other contamination.

The most probable origin of alien species brought into the *Arctowski* is Europe although it is not the only source. Cargo is loaded mainly from disturbed areas, like farms and holding areas in ports, where both the abundance and diversity of invasive species from elsewhere in the world is likely to be high (Slabber and Chown 2002; Chwedorzewska 2009). A large number of ships inevitably travel from the Northern Hemisphere with some working consecutive Antarctic/Arctic summers to take advantage of ice-strengthened or ice-breaking capabilities (Enzenbacher 1994). The ship supplying the Polish Antarctic Station also operates in the boreal summer in the Arctic for six months before departing for Antarctica (Chwedorzewska 2009). This can increase the probability of introduction of non-native species with pre-adaptations to survive in cold environments. Moreover, most research stations are situated in the least climatically extreme locations and almost always on ice-free ground (Bölter and Stonehouse 2002; Frenot *et al.* 2005). The surrounding of the Polish Antarctic Station seems to be one of the most favourable areas in maritime Antarctic. The *Arctowski* oasis covers a big ice-free area more than 21 km^2, with a constant flow of fresh water throughout almost the entire summer season which promotes the development of a heterogeneous ecosystem (Rakusa-Suszczewski 2003; Olech 2004; Bednarek-Ochyra *et al.* 2008; Ochyra *et al.* 2008). The climate of this region, compared with other parts of the Antarctic, is relatively mild (King and Turner 2007). The recent climate change in region of the western coast of Antarctic Peninsula and Scotia Arc archipelagos (Turner *et al.* 2005, 2009) may extend the period of physiological activity of terrestrial species (Convey 2006). Ameliorating environmental conditions along with intensified human activities are likely to reduce the establishment barriers that have historically prevented colonization by potentially invasive species and which could support a rapid increase of biodiversity of alien species in Antarctica. But hopefully, the most probable source of alien organisms is Poland which climatically differ significantly from South Shetlands the meteorological condition (Table 3).

Indigenous free-living entomofauna is extremely rare in Antarctica and only two species of Diptera (Chironomidae) are found in the western Antarctic Peninsula and associated archipelagoes (Convey and Block 1996, Vernon *et al.* 1998). Their distribution is limited, but it does overlap: *Parochlus steinenii* (Gerke) reaches 62°37'S (Edwards and Usher 1985) and *Belgica antarctica* Jacobs reaches 68°17'S (Usher and Edwards 1984). A number of observations have already been published on unintentional importation of alien plants, fungi or insects which survived and become associated with Antarctic research stations (*e.g.* Hughes *et al.* 2005; Chwedorzewska 2008, 2009; Hughes and Worland 2010). Some non-native terrestrial invertebrates were already introduced to the Antarctic *e.g.*: *Eretmoptera murphyi* Schaeffer and *Christensenidrilus blocki* Dozsa-Farkas and Convey (Hughes and Worland 2010; Hughes *et al.* 2012) found on Signy Station, South Orkney Islands (Edwards and Greene 1973; Edwards 1979) or *Trichocera maculipennis* found on Artigas Station (King George Island, South Shetlands) (Greenslade *et al.* in press). The majority of Antarctic indigenous organisms are characterized by a lack of competitive ability, so the appearances in this very simple ecosystem of new species possessing several pre-adaptations, which allow them survive the Antarctic conditions, may have unpredictable consequences (Chwedorzewska and Bednarek 2011; Hughes *et al.* 2012).

It can be concluded that it is very hard alien organisms to the Antarctic but probability that imported invertebrates will become established and spread is considered rather small. In most cases they are temperate taxa and even if any species would be able to survive certain period in the indoor conditions of a station, most of them would be unable to complete their life cycle and establish a stable population outside. A reduction of alien organisms pressure is possible by an introduction of some simple procedures allowing to minimialize their transport when supplying Antarctic stations (www.ats.aq/documents/atcm34/ww/atcm34_ww004_e.pdf).

Acknowledgments. — This research project was supported by the Ministry of Scientific Research and Higher Education by a grant IPY/27/2007. The authors would like to thank all persons involved in collecting materials during XXX, XXXI and XXXII Polish Antarctic Expeditions. We would like to thank two anonymous reviewers for constructive advice that has improved our paper.

References

BARNES D.K.A. 2002. Invasions by marine life on plastic debris. *Nature* 416: 289–291.

BARNES D.K.A. and FRASER K.P. 2003. Rafting by five phyla on manmade flotsam in the Southern Ocean. *Marine Ecology – Progress Series* 262: 289–291.

BARNES D.K.A., WARREN N., WEBB K., PHALAN B. and REID K. 2004. Polar pedunculate barnacles piggy-back on pycnogona, penguins, pinniped seals and plastics. *Marine Ecology – Progress Series* 284: 305–310.

BARGAGLI R., BROADY P.A. and WALTON D.W.H. 1996. Preliminary investigation of the thermal biosystem of Mount Rittmann fumaroles (northern Victoria Land, Antarctica). *Antarctic Science* 8: 121–126.

BEDNAREK-OCHYRA H., VÁŇA J., OCHYRA R. and LEWIS-SMITH R.I. 2000. *The liverwort flora of Antarctica*. Polish Academy of Science, Institute of Botany, Kraków 1–238.

BÖLTER M. and STONEHOUSE B. 2002. Uses, preservation, and protection of Antarctic Coastal Regions. *In*: L. Beyer and M. Bölter (eds) Geoecology of Antarctic ice-free coastal landscapes. *Ecological Studies* 154: 393–407.

CIAPUTA P. and SALWICKA K. 1997 Tourism at Antarctic *Arctowski* Station 1991–1997: policies for better management. *Polish Polar Research* 18: 227–239.

CLARKE A., BARNES D.K.A. and HODGSON D.A. 2005. How isolated is Antarctica? *Trends in Ecology and Evolution* 20: 1–3.

COULSON S.J., HODKINSON I.D., WEBB N.R. and HARRISON J.A. 2002. Survival of terrestrial soil-dwelling arthropods on and in seawater: implications for trans-oceanic dispersal. *Functional Ecology* 16: 353–356.

CHOWN S.L. and CONVEY P. 2007. Spatial and temporal variability across life's hierarchies in the terrestrial Antarctic. *Philosophical Transactions of the Royal Society B* 362: 2307–2331.

CHEN J. and BLUME H.P. 1995. Impact of human activities on the terrestrial ecosystem of Antarctica: a review. *Polarforschung* 65: 83–92.

CHOWN S.L., HUISKES A.H.L., GREMMEN N.J.M., LEE J.E., TERAUDS A., CROSBIE K., FRENOTE Y., HUGHES K.A., IMURA S., KIEFER K., LEBOUVIERH M., RAYMOND B., TSUJIMOTO M., WAREC C., Van DE VIJVERK B. and BERGSTROM D.M. 2012. Continent-wide risk assessment for the establishment of nonindigenous species in Antarctica. *Proceedings of the National Academy of Sciences* 109: 4983–4943.

CHWEDORZEWSKA K.J. 2008. *Poa annua* L. in Antarctic – searching for the source of introduction. *Polar Biology* 31: 263–268.

CHWEDORZEWSKA K.J. 2009. Terrestrial Antarctic ecosystems in the Changing World: an overview. *Polish Polar Research* 30: 263–273.

CHWEDORZEWSKA K.J. and BEDNAREK P.T. 2011. Genetic and epigenetic studies on populations of *Deschampsia antarctica* Desv. from contrasting environments at King George Island (Antarctic). *Polish Polar Research* 32: 15–26.

CHWEDORZEWSKA K.J. and BEDNAREK P.T. 2012. Genetic and epigenetic variation in a cosmopolitan grass (*Poa annua* L.) from Antarctic and Polish populations. *Polish Polar Research* 33: 63–80.

CHWEDORZEWSKA K.J. and KORCZAK M. 2010. Human impact upon the environment in the vicinity of *Arctowski* Station, King George Island, Antarctica. *Polish Polar Research* 31: 45–60.

CONVEY P. 2006. Antarctic climate change and its influences on terrestrial ecosystems. *In*: D.M. Bergstrom, P. Convey and A.H.L. Huiskes (eds) *Trends in Antarctic terrestrial and limnetic ecosystems: Antarctica as a global indicator*. Springer, Dordrecht: 253–272.

CONVEY P., BINDSCHADLER R., DI PRISCO G., FAHRBACH E., GUTT J., HODGSON D.A., MAYEWSKI P.A., SUMMERHAYES C.P., TURNER J. and THE ACCE CONSORTIUM 2009. Antarctic climate change and the environment. *Antarctic Science* 21: 541–563.

CONVEY P. and BLOCK W. 1996. Antarctic Diptera: Ecology, physiology and distribution. *European Journal of Entomology* 93: 1–13.

CUBA-DÍAZ M., TRONCOSO J.M., CORDERO C., FINOT V.L. and RONDANELLI-REYES M. 2012. *Juncus bufonius*, a new non-native vascular plant in King George Island, South Shetland Islands. *Antarctic Science* doi: 10.1017/S0954102012000958.

EDWARDS J.A. 1979. An experimental introduction of vascular plants from South Georgia to the Maritime Antarctica. *British Antarctic Survey Bulletin* 49: 73–80.

EDWARDS J.A. and GREENE D.M. 1973. The survival of Falkland Is transplants at South Georgia and Signy I., South Orkney Is. *British Antarctic Survey Bulletin* 34: 33–45.

EDWARDS M. and USHER M.B. 1985. The winged Antarctic midge *Parochlus steinenii* (Gerke) (Diptera: Chironomidae) in the South Shetland Islands. *Biological Journal of the Linnean Society* 26: 83–93.

ENZENBACHER D.J. 1994. Antarctic tourism: an overview of 1992/93 season activity, recent developments, and emerging issues. *Polar Record* 30: 105–116.

FRENOT Y., CHOWN S.L., WHINAM J., SELKIRK P.M., CONVEY P., SKOTNICKI M. and BERGSTROM D.M. 2005. Biological invasions in the Antarctic: extent, impacts and implications. *Biological Reviews* 80: 45–72.

GREENSLADE P. 2002. Assessing the risk of exotic Collembola invading subantarctic islands: prioritising quarantine management. *Pedobiologia* 46: 338–344.

HEADLAND R. 1989. *Chronological list of Antarctic expeditions and related historical events*. Cambridge University Press, Cambridge: 601 pp.

HULL B.B. and BERGSTOM D.M. 2006. Antarctic terrestrial and limnetic ecosystem conservation and management. *In*: D.M. Bergstrom, P. Convey and A.H.L. Huiskes (eds) *Trends in Antarctic terrestrial and limnetic ecosystems*. Springer, Dordrecht: 317–340.

HUGHES K.A. and CONVEY P. 2010. The protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. *Global Environmental Change* 20: 96–112.

HUGHES K.A. and CONVEY P. 2012. Determining the native/non-native status of newly discovered terrestrial and freshwater species in Antarctica – Current knowledge, methodology and management action. *Journal of Environmental Management* 93: 52–66.

HUGHES K.A. and WORLAND M.R. 2010. Spatial distribution, habitat preference and colonisation status of two alien terrestrial invertebrate species in Antarctica. *Antarctic Science* 22: 221–231.

HUGHES K.A., CONVEY P., MASLEN N.R. and SMITH R.I.L. 2010a. Accidental transfer of non-native soil organisms into Antarctica on construction vehicles. *Biological Invasions* 2: 875–891.

HUGHES K.A., LEE J.E.¸ WARE C., KIEFER K. and BERGSTROM D.M. 2010b. Impact of anthropogenic transportation to Antarctica on alien seed viability. *Polar Biology* 8: 1125–1130.

HUGHES K.A., OTT S., BÖLTER M. and CONVEY P. 2006. Colonisation Processes. *In*: D.M. Bergstrom, P. Convey and A.H.L. Huiskes (eds) *Trends in Antarctic terrestrial and limnetic ecosystems: Antarctica as a global indicator*. Springer, Dordrecht: 35–54.

HUGHES K.A., WALSH S., CONVEY P., RICHARDS S. and BERGSTROM D.M. 2005. Alien fly populations established at two Antarctic research stations. *Polar Biology* 28: 568–570.

HUGHES K.A., LEE J.E., TSUJIMOTO M., IMURA S., BERGSTROM D.M., WARE C., LEBOUVIER M., HUISKES A.H.L., GREMMEN N.J.M., FRENOT Y., BRIDGE P.D. and CHOWN S.L. 2011. Food for thought: Risks of non-native species transfer to the Antarctic region with fresh produce. *Biological Conservation* 144: 2821–2831.

HUGHES K.A., WORLAND M.R., THORNE M.A.S. and CONVEY P. 2012. The non-native chironomid *Eretmoptera murphyi* in Antarctica: erosion of the barriers to invasion. *Biological Invasions* 15: 269–281.

KING J.C. and TURNER J. 2007. *Antarctic meteorology and climatology*. Cambridge University Press, Cambridge: 409 pp.

LAMERS M. 2009. *The future of tourism in Antarctica: challenges for sustainability*. Ph.D. thesis. University of Maastricht, Maastricht: 235 pp.

LEE J.E. 2008. *Alien species and propagules in the Antarctica: movements through space and time*. Ph.D. thesis. Stellenbosch University. Cape Town: 171 pp.

LEE J.E. and CHOWN S.L. 2009a. Breaching the dispersal barrier to invasion: quantification and management. *Ecological Applications* 19: 1944–1959.

LEE J.E. and CHOWN S.L. 2009b. Quantifying the propagule load associated with the construction of an Antarctic research station. *Antarctic Science* 21: 471–475.

LEWIS P.N., RIDDLE M.J. and SMITH S.D.A. 2005. Assisted passage or passive drift: a comparison of alternative transport mechanisms for non-indigenous coastal species into the Southern Ocean. *Antarctic Science* 17: 183–191.

LEWIS SMITH R.I. 1984. Colonization and recovery by cryptogams following recent volcanic activity on Deception I., South Shetland I. *British Antarctic Survey Bulletin* 62: 25–51.

LEWIS SMITH R.I. 1991. Exotic sporomorpha as indicators of potential immigrant colonists in Antarctica. *Grana* 30: 313–324.

LEWIS SMITH R.I. 1993. Dry costal ecosystems of Antarctica. *In*: E. van der Maael (ed.) *Ecosystems of the world, 2A; dry coastal ecosystems, polar regions and Europe*. Elsevier, Amsterdam: 51–57.

LEWIS SMITH R.I. 1996. Introduced plants in Antarctica: potential impacts and conservation issues. *Biological Conservation* 76: 135–146.

LITYŃSKA-ZAJĄC M., CHWEDORZEWSKA K.J., OLECH M., KORCZAK-ABSHIRE M. and AUGUSTYNIUK-KRAM A. 2012. Diaspores and phyto-remains accidentally transported to the Antarctic Station during three expeditions. *Biodiversity and Conservation* 21: 3411–3421.

MARSHALL W.A. 1996. Biological particles over Antarctica. *Nature* 383: 680.

MOLINA-MONTENEGRO M.A., CARRASCO-URRA F., RODRIGO C., CONVEY P., VALLADARES F. and GIANOLI E. 2012. Occurrence of the non-native annual bluegrass on the Antarctic mainland and its negative effects on native plants. *Conservation Biology* 26: 717–723.

OCHYRA R. 1998. *The moss flora of King George Island, Antarctica*. Polish Academy of Science. W. Szafer Institute of Botany, Cracow: 278 pp.

OLECH M. 1996. Human impact on terrestrial ecosystems in west Antarctica. *Proceedings of the NIPR Symposium on Polar Biology* 9: 299–306.

OLECH M. 2004. *Lichens of King George Island, Antarctica*. The Institute of Botany of the Jagiellonian University, Cracow: 1–391.

OLECH M. and CHWEDORZEWSKA K.J. 2011. The first appearance and establishment of alien vascular plant in natural habitats on the forefield of retreating glacier in Antarctica. *Antarctic Science* 23: 153–154.

OSYCZKA P. 2010. Alien lichens unintentionally transported to the *Arctowski* station (South Shetlands, Antarctica). *Polar Biology* 33: 1067–1073.

POLAND J.S., RIDDLE M.J. and ZEEB B.A. 2003. Contaminants in the Arctic and Antarctic: a comparison of sources, impacts, and remediation options. *Polar Record* 39: 369–383.

PUGH P.J.A. 1994. Non-indigenous Acari of Antarctica and the sub-Antarctic islands. *Zoological Journal of the Linnean Society* 110: 207–217.

RAKUSA-SUSZCZEWSKI S. 2003. Functioning of the geoecosystem for the west side of Admiralty Bay (King George Island, Antarctica): outline of research at Arctowski Station. *Ocean and Polar Research* 25: 653–662.

SLABBER S. and CHOWN S.L. 2002. The first record of a terrestrial crustacean, *Porcellio scaber* (Isopoda, Porcellionidae), from sub-Antarctic Marion I. *Polar Biology* 25: 855–858.

STONEHOUSE B. 1999. Antarctic shipborne tourism: facilitation and research at *Arctowski* Station, King George Island. *Polish Polar Research* 20: 65–75.

TERAUDS A., CHOWN S.L., MORGAN F., PEAT H.J., WATTS D.J., KEYS H., CONVEY P. and BERGSTROM D.M. 2012. Conservation biogeography of the Antarctic. *Diversity and Distributions* 18: 726–741.

TSUJIMOTO M. and IMURA S. 2012. Does a new transportation system increase the risk of importing non-native species to Antarctica? *Antarctic Science* 24: 441–449.

TURNER J., COLWELL S.R., MARSHALL G.J., LACHLAN-COPE T.A., CARLETON A.M., JONES P. D., LAGUN V., REID P.A. and IAGOVKINA S. 2005. Antarctic climate change during the last 50 years. *International Journal of Climatology* 26: 279–294.

TURNER J., BINDSCHADLER R., CONVEY P., DI PRISCO G., FAHRBACH E., GUTT J., HODGSON D., MAJEWSKI P. and SUMMERHAYES C. 2009. *Antarctic Climate Change and the Environment – A contribution to the International Polar Year 2007–2008*. SCAR Scott Polar Research Institute, Victoire Press, Cambridge: 526 pp.

USHER M.B. and EDWARDS M. 1985. A dipteran from south of the Antarctic Circle: *Belgica antarctica* (Chironomidae) with a description of its larva. *Biological Journal of the Linnean Society* 23: 83–93.

VERNON P., VANNIER G. and TREHEN P. 1998. A comparative approach to the entomological diversity of polar regions. *Acta Oceanologica* 19: 303–308.

WHINAM J., CHILCOTT N. and BERGSTROM D.M. 2005. Sub-Antarctic hitchhikers: expeditioners as vectors for the introduction of alien organisms. *Biological Conservation* 121: 207–219.

Received 7 August 2012
Accepted 10 January 2013