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Summary

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The Impact of Human Activities on Soil Organisms of the Maritime Antarctic and the Introduction of Non-Native Species in Antarctica

Summary

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Summary

A strongly growing source of anthropogenic impacts on the Antarctic environment is research and tourism. Today more than 40 different companies from approximately 15 countries offer Antarctic cruises with the possibility of land excursions, mainly within the northern Antarctic Peninsula. Since 1989/1990 the number of visitors to Antarctica has increased exponentially, and during the last 10 years **more than 20,000 tourists visit Antarctica per year**. However, tourism is not evenly distributed throughout all destinations. The increase in visitor numbers has **concentrated on only a few regions** (mainly the South Shetland Islands and the north-western Antarctic Peninsula) and specific locations, i.e. Whalers Bay (Deception Island), Neko Harbour or Half Moon Island.

The number of persons staying in Antarctica for reasons of research is considerably less than the number of tourists. **Presently, 80 research stations are maintained by 29 countries, in which approximately 4,300 persons live and work in summer and about 1,000 in winter**. The environmental stress caused by research personnel can therefore be considered to be less than that caused by tourists. However, the environment impacts are considerably more concentrated and - more importantly – long-term around research stations.

The cumulative environmental impacts in the vicinity of research stations have already been the subject of previous studies. The majority of such scientific studies concentrated on marine ecosystems or on the consequences of chemical pollution (accidents, waste dumps or waste-water). The widely distributed breading and moulting sites of vertebrate animals such as penguins, seals and sea birds are common research objects as well as the goal of touristic excursions. Therefore, many studies have also investigated the impacts of human activities on Antarctic vertebrates.

The preferred Antarctic breading and moulting sites of penguins, seals and sea birds are generally ice-free areas. Only in such ice-free areas can soils and, consequently, soil organisms exist. Since touristic excursion destinations are concentrated especially in these areas, such sites are especially susceptible to disturbance by and impacts of human activities. Furthermore, Antarctic soils are considered to be particularly sensitive to anthropogenic disturbances. Nonetheless, **only very few studies on the effects of human activities on Antarctic soils and soil organisms exist.**

Compared with habitats in other latitudes, e.g. the tropics or temperate regions, the **terrestrial Antarctic fauna and flora are very species-poor and weakly structured**. Antarctic botanical communities generally consist only of cryptogams (mosses, liverworts and lichens), while only two higher (= flowering) plant species occur naturally. The endemic terrestrial invertebrate fauna in Antarctica is composed merely of Diptera (flies, only two species), Acari (mites), Collembola (springtails), Nematoda (roundworms), Rotifera (rotifers, wheel animals), Tardigrada (water bears) and Protozoa (single-celled animals). The habitat of the terrestrial invertebrate fauna is found primarily only in ice-free areas. The faunal communities, especially of continental Antarctica, belong to the simplest on earth.

The few investigations of anthropogenic impacts on the vegetation mostly attest to direct damage by trampling, but also to indirect impacts, for instance due to an influence on the soils beneath the vegetation. Although many basic scientific studies of the Antarctic soil fauna exist, hardly any investigations of the effects of human activities on Antarctic terrestrial invertebrate communities have been carried out. The few studies that do exist could show

negative effects already at very low levels of anthropogenic influence. However, mostly only the influence on total densities of entire animal groups was studied. The influence on other biodiversity parameters is unknown. Furthermore, almost all scientific studies on Antarctic soil organisms were carried out in spatially relatively limited areas and concentrated only on specific taxonomic groups. **Studies of anthropogenic influences on larger regional scales and on multiple soil-borne animal groups are extremely rare.**

In contrast, the potential or actual introduction of non-native species into Antarctic habitats has been more intensively studied. The **clear danger of an anthropogenic introduction of species foreign to Antarctica**, mainly by tourists, has been stressed many times. The limited biodiversity and simplicity of terrestrial species communities in Antarctica render them potentially sensitive to colonization by introduced species. Furthermore, the fact that many tourists visit Subantarctic islands before entering Antarctica increases this danger.

Considering the large number of tourists that visit the few ice-free areas of Antarctica, the influence of humans and thus also touristic activities on Antarctic soils and soil organisms can be considerable. Therefore, **the present study investigated potential anthropogenic impacts on a major portion of the species communities in Antarctic soils (with the exception of microorganisms) in a larger region strongly affected by tourism (the Antarctic Peninsula)**. Localities were chosen as study sites that were frequented by tourists or are often visited by station personnel and researchers. The study aimed at answering the following questions: (1) Have non-native soil-animal species been introduced into areas of high human activities? (2) How effective are existing bio security measures against the introduction of soil organisms? (3) Can a direct anthropogenic impact on Antarctic soil-organism communities be identified? (4) Which habitat parameters and interactions between human activities and habitat parameters influence the occurrence and distribution of Antarctic soil organisms? (5) Do changes in species distribution caused by humans lead to a "homogenization" and thus to a reduction of the diversity of the species composition in various Antarctic habitats?

The main criterion in the choice of study sites was the regular presence of humans. Therefore, especially **sites of land excursions of touristic cruises as well as areas strongly frequented by station and research personnel along Antarctic Peninsula were considered as study sites.** The fieldwork was performed during land excursions of various Antarctic tours of three cruise ships: the MS Hanseatic, MS Bremen (both Hapag-Lloyd GmbH Hamburg) as well as the MS Delphin (Hansatours GmbH Hamburg). During multiple cruises of these ships, the scientific personnel as well as other scientists on board these ships carried out the sampling. Members of the workgroup of Hans-Ulrich Peter (Institute of Ecology of the Friedrich-Schiller-University, Jena, Germany) sampled further study sites on the Fildes Peninsula of King George Island during their yearly research trips there.

A total of 13 localities were sampled: Arctowski Station (King George Island), Biologenbucht and two sites at Punta Christian on the Fildes Peninsula (King George Island), Ardley Island, Halfmoon Island, Hannah Point on Livingston Island, Whalers Bay and Telefon Bay on Deception Island, Devil Island and Paulet Island in the Weddle Sea as well as Neko Harbour and Petermann Island on the Antarctic Peninsula. Of these, nine were investigated in the first study year (2010), seven in the second year (2011) and only three in both study years.

A standardized sampling design for the fieldwork ensured that (1) the local habitat characteristics were taken into consideration during sampling, (2) sampling provided the necessary database for a thorough statistical analysis of the results and (3) the workload could be realized within the framework of the project resources. The sampling design contained the following hierarchy levels: “locality” (= study site), “treatment” (= anthropogenically influenced and non-influenced plots within a locality), “areas” (= different study plots within a treatment, preferentially three anthropogenically influenced and three non-influenced plots within a locality) and individual soil samples within an area (four per area; regularly distributed within a square meter). The selection of the study plots occurred pair-wise: an anthropogenically influenced and a non-influenced plot that were otherwise equivalent regarding soil substrate, vegetation etc. Detailed written instructions for the fieldwork as well as a standardized fieldwork protocol were developed for the external samplers to ensure that all results were comparable.

In the two study years, a total of 327 individual samples were taken and processed. The soil samples were immediately packaged in common household plastic freezer bags, sealed and stored cool during the further cruise. In addition to the soil samples, additional vegetation samples were taken, packaged in paper bags and also stored cooled and dry. After being taken from the field, all samples were flown to Germany as soon as possible, where further processing took place.

After the samples arrived in Görlitz, Germany, the vegetation samples were first forwarded to the project’s botanist (V. Otte, Görlitz). The vegetation was studied mainly as a biotic habitat factor. Besides the species-specific determination of the occurring taxa in each study plot, the degree of vegetational cover as well as the plant community for each study area was ascertained.

The soil animals were extracted from each individual soil sample with the help of two different methods. A wet extraction modified from Baermann was used for the microfauna (Nematoda and Tardigrada) and a dry extraction according to MacFadyen for the mesofauna (Collembola and the various mite groups). Extraction of the soil animals preferably began on the same day or at the latest within very few days after arrival of the samples in Germany. After the MacFadyen extraction was ended (after 10 days), the extracted samples were transferred to 70% ethanol and stored for three weeks to conserve the soil animals. The extracted nematodes and tardigrades were removed daily and the animals killed with hot (60°C) water and conserved in 2% triethanolamine-formalin solution.

After extracting and conserving the animals, these were subsequently sorted under the stereomicroscope at maximally 50x magnification into the major (= higher) taxonomical groups (Collembola, Actinedida, Oribatida and Gamasina; Nematoda and Tardigrada). Determination of the soil animals was carried out by European taxon specialists: Nematoda (K. Hohberg, Görlitz), Tardigrada (S. McInnes, Cambridge). Collembola (M. Potapov, Moscow), as well as the mite groups Actinedida (D. Russell, Görlitz), Oribatida (A. Bruckner, Vienna) and Gamasina (A. Christian, Görlitz). For species determination, microscopic slides of the individuals of the respective animal group were prepared and the taxa identified under the light microscope at maximally 1000x magnification, preferably to species level.

For a more detailed characterization of the soil of each sample, the following soil parameters were assessed: soil temperature (at the time of sampling), soil moisture, pH value, soil texture, organic carbon and C/N ratio. The goal of the soil analyses was to ensure the comparability of the different plot types (anthropogenic influence and no influence) in regard to general habitat parameters as well as to identify habitat characteristics that possibly also influence the faunal communities.

The recorded densities of each species of each sample was extrapolated to number of individuals per 100 cm^3 substrate in order to guarantee the standardization of the differently sized samples and thus the comparability of all data. To determine whether significant differences in densities or species richness existed between localities and especially between anthropogenically influenced and non-influenced plots within a locality, the data was subjected to non-parametric variance analyses (ANOVA). To identify possible relationships between soil animal species and habitat parameters, a non-parametric Spearmann correlation analysis was carried out on the zoological data and all abiotic soil data as well as the vegetation data. To determine whether the occurrence of individual species as well as entire species communities was influenced by background habitat parameters (i.e., soil moisture, soil temperature, content of organic matter etc.), covariance analyses (ANCOVA) were performed. The similarity between the recorded animal communities was characterized by the NMDS procedure (non-metric multidimensional scaling), which determined whether the factors "locality" and "treatment" (= anthropogenic influence or not) influenced the structure of the total animal communities. Whether the factors "locality" and "treatment" had a *significant* influence on the similarity of the recorded animal communities was tested with the PERMANOVA procedure. Finally, a CAP analysis („canonical analysis of principal coordinates") determined whether the factor "treatment" alone had a significant influence on the total animal communities.

The characteristics of the study soils reflected typical maritime Antarctic conditions. The measured soil temperatures indicated relatively cool substrates, while the moisture values revealed (for Antarctica) relatively moist soils. The soil textures of all localities were usually sandy and/or gravelly, and the pH values of the sampled substrates mostly revealed weakly to moderately acidic conditions. The sampled soils were generally poor in organic matter. The C/N ratios of the soils, however, indicated that the organic matter was of relatively high quality. In total, a general north-south gradient of decreasing soil-parameter values (soil moisture, content of organic matter, C/N ratio) as well as a increasing pH values was observed. Significant differences between the soil parameters of influenced and non-influenced plots within the individual localities were rare. When differences were statistically significant, then the absolute differences were usually so low as to most likely be biologically not relevant.

No vegetation existed in the study sites on Devil Island, Petermann Island, Telefon Bay, Whalers Bay (in the year 2011) and Neko Harbour. Otherwise, vegetation was found in eight of the 13 localities. In two cases (Paulet Island, Halfmoon Island), the vegetation only consisted of pure stands of the green algae *Prasiola crispa*. The recorded vegetation in the other sites mainly consisted of cryptogams. In total, two species of flowering plants, 24 lichens species, 19 mosses, three liverworts and one species of macroalgae were proven. All of these species were found in localities of the South Shetland Islands (King George Island and Ardley Island), a few species furthermore on Halfmoon Island and in Whalers Bay (in the year 2010). All of these species had been previously known to occur in the South Shetland Islands. While the recorded flowering plants represented all of the only two naturally occurring indigenous Antarctic species, only a small portion of the lichens and mosses known to occur in the study area were identified in this study. This is due, on the one hand, to the fact that a large proportion of the Antarctic cryptogam species inhabit rocky habitats, which was not the subject of the present studies. On the other hand, the densities of the major portion of the occurring species are very low in

Antarctica and therefore the likelihood of their collection during the present study – which was not specifically oriented towards botanical aspects - is also low. No species was identified that had not been hitherto recorded in Antarctica. The likelihood of discovering introduced plant species with the methods used in the present study is, however, small, especially considering that such species usually occur in very low densities.

The botanical results confirm the comparability of the human influenced and non-influenced plots. Striking differences in the diversity of the anthropogenically influenced and non-influenced areas could not be proven. In individual localities, a minimal shift in dominance from pleurocarpe to acrocarpe mosses was found in influenced areas of some localities, but then again shifts in the opposite direction in other localities, both of which could not be statistically confirmed. Trampling in *Sanionia* communities created single open-soil areas, in which these mosses could assert themselves against more strongly competitive species. In contrast, the trampling-sensitive fruticose lichens appeared to be more common in the non-influenced areas. The photo documentation could furthermore show a promotion of the algae *Prasiola crispa* to the detriment of other species in areas frequented by humans, whereby stuntedly growing *Deschampsia* almost disappeared between the *Prasiola* mats. In the non-influenced areas, however, *Deschampsia* represented the dominant species.

More than 320,000 individuals were recorded among all the studied animal groups. **The majority of individuals were found among the Nematoda (> 255.000 individuals), Tardigrada (> 30.000) and Collembola (> 25.000). A total of 98 species were proven, mostly Nematoda (40 species), Actinedida (25), Tardigrada (14) and Collembola (11).**

The sampled mesofauna (= Collembola, Actinedida, Oribatida and Gamasina) can be considered to be typical for Maritime Antarctica. Almost all determined species had been previously recorded in the maritime Antarctic. Some of the registered taxa are even endemic to Antarctica. However, no locally endemic species were detected. Also, the present study did not increase the known distributional ranges of the recorded species.

Spatial distribution of the study sites within the maritime Antarctic was somewhat limited. Nonetheless, all collembolan species known to occur in Maritime Antarctica were found in the present study. In contrast, by no means all of the mite species known to occur in the Antarctic Peninsula were found in the current study. This is most likely due to the fact that the studied substrates differed from those of previous species surveys. These earlier studies usually investigated many different microhabitats or concentrated on collecting underneath stones etc. With over 40 determined species, the present study nonetheless recorded a large portion of the known maritime Antarctic mesofauna. The species richnesses and densities of the mesofauna registered in the various study sites correspond to those found in previous studies. Only some locations (Paulet Island, Devils Island or Petermann Island) were extremely species- and individual-poor compared to other locations or earlier studies.

The majority of previous studies on the Antarctic microfauna (Nematoda and Tardigrada) did not concentrate on the soil-borne fauna, but rather investigated the fauna in moss cushions and lichens. Therefore, the fact that 19 of the 40 nematode species registered in the current study have not been previously recorded or described in Antarctic investigations cannot be considered to be an indication that these previously unknown species were introduced by tourists. Rather, it is quite possible that these species have simply been overlooked in the past, due to their very small-scaled distribution and the limited number of detailed nematode studies in maritime Antarctica. Especially for the Tardigrada, the current study was able to include a number of new locations and habitats to previous investigations and thereby increase existing knowledge of the species composition of many localities within Maritime Antarctica. The current study could add at least six species to the known Antarctic Tardigrada fauna.

In both study years, highly significant differences between the faunas of the various localities were ascertained, both concerning species richness and densities of all animal groups. The strong differences between localities are most likely due to local habitat differences (characteristics of the respective coasts, slope exposition, soil parameters, vegetation etc.). **Significantly decreasing total densities from the northern to southern localities were evident**, especially among the microfauna. The highest individual densities and species richness were found in the year 2010 in the northernmost study sites on King George Island. In 2011 the highest nematode numbers were exceptionally found in the soils of the relatively southern Paulet Island. However, these high densities were attributed to the massive population growth of a single species, *Rhomborhabditis* cf. *teres*, most likely caused by the relatively high nitrogen content and presumed large bacterial food-resource supply in the ornithogenic soils on Paulet Island. The North to South gradient was not so obvious among the densities of the mesofauna, although their highest densities were found in the localities of the South Shetland Islands. Decreasing species richness from the northern to the southern localities were ascertained among all animal groups. However, this trend cannot be viewed as being a general truth, since various studies in the past could record relatively species-rich soil animal communities in far more southern regions of the maritime Antarctic.

The following criteria were used for the evaluation of recorded species which had not been previously found in Antarctica as being non-native or not: previously not known from Antarctic habitats (or already known as being introduced), known as being cosmopolitically distributed or originating in Europe, parthenogenetic reproduction and/or the highest densities being found in barren soils without vegetation. The present study could not provide direct proof of species transfer by humans. Therefore, identified non-native species were only considered to be *potentially* introduced by humans.

Among the Tardigrada and Nematoda, a number of species were identified that were not previously known from Antarctica. Their status as being native or non-native could not be evaluated, since these species are new to science and/or have probably simply not been recorded in the past due to lacking comparable studies. Among the Nematoda five species are reported for the first time from Antarctica. These species are related to morphologically very similar species that are distributed worldwide. It remains open whether these current records truly belong to these widely distributed species or whether they are only related species, whose distribution is limited to Antarctica. Concerning the Tardigrada no indication of a species' introduction was found. Nonetheless, the current study provided the proof of many potentially new species. Since the current analysis have shown that these records do not belong to known species, they indicate more that they belong to species native to maritime Antarctica rather than being introduced species.

In contrast, **eight species of the Collembola and Actinedida were identified as being non-native and potentially introduced. The highest number of non-native species was recorded from Deception Island.** The current study increases the number of collembolan species known to occur on Deception Island to 14, among which seven - in other words 50% - are non-native. This high number of non-native species can be primarily attributed to the geothermal activity of the island, which provides warm and moist habitat conditions. The long history of human presence on Deception Island and the presently high degree of tourism can be seen as a further cause of the colonization of the island by non-native species. **The second highest number of potentially non-native species as well as their second highest densities were found in Neko Harbour.** This locality also receives one of the highest numbers of visitors per year in the maritime Antarctic, which again suggests a potential anthropogenically influenced distribution of these species. Many of these species were recorded in many other touristic excursion sites, even if only in few specimens. Therefore, **an increasing distribution of these non-native species promoted by human activities appears to be highly probable.** Almost all non-native species of the Actinedida and Collembola showed no significant density differences between touristically influenced and non-influenced coastal areas. This further indicates the species' potential to be distributed by human activities.

The biosecurity measures routinely used aboard the MS Hanseatic to prevent species transfer could be shown to be insufficiently efficient. They were especially ineffective in areas which were particularly muddy (and with high contents of penguin droppings etc.) or which harbored species- and individual-rich soil animal communities. For instance, large differences existed between the two sets of boot-washing samples. After the land excursion on South Georgia, a strong growth and activity of microorganisms could be observed in 100% of the samples. The microbial activity was most likely promoted by the penguin droppings on the soles of the visitors' boots, which illustrates the biological vitality of the substrate. In 30% of the boot samples, remains of feathers and other detritus could be found, while 60% of the samples contained soil particles. Pieces of plants were found in more than 50% of the samples. Most importantly, more than half of the samples contained soil animals. In contrast, the samples taken after the excursion on Deception Island were comparatively clean. Although soil particles were found in almost all cases (80% of the samples), microbial activity was only exceptionally (10%) observed. Feather and plant remains were found in 20% of the samples. Two nematode individuals could be determined in two different samples. **The transportation of soil organisms by the footwear of visitors could thus be proven, despite the "bootwashing" measures.** Due to the conservation of the samples, it is unknown whether the individuals remained alive and could further exist after their transfer by visitors' boots. Nonetheless, these results clearly illustrate the high biological *potential* of soil remains on visitors' footwear and the necessity of preventive biosecurity measures such as "bootwashing". The lacking efficiency of the biosecurity measures is not primarily due to the methods themselves, but may be attributed to poor human behaviour while executing these measures (i.e., inadequate use or control of their use).

In the current study, the known distribution of the recorded species in the maritime Antarctic was described as well as their previously elucidated ecological preferences. The results of the correlation and covariance analyses performed here could confirm and increase the present knowledge of the ecological preferences of the investigated species. Both analysis could show an essential relationship between the soil fauna and vegetation cover: **the recorded soil animal communities were individual- and species-richer the denser the vegetational cover became.** The positive vegetational effect was found among all taxonomic groups. An increase in population sizes with increasing vegetational cover could also be determined among many individual species. The covariance analyses revealed significantly higher densities especially at medium levels of vegetation cover. This illustrates **the importance of vegetation as a habitat**

for the Antarctic soil fauna, regardless of how strongly developed the vegetation is. Soil substrates with vegetation offer spatially and climatically advantageous habitat than more purely mineral sand, gravel or fellfield substrates.

The correlation results confirmed the possible limitation of the fauna by soil moisture, since many taxonomical major groups as well as many individual species developed their highest densities (as well as species richness within the major groups) at higher soil moisture levels. This effect was strongest among the Collembola, Actinedida and Nematoda. Very distinct was furthermore the relationship between the Collembola, Oribatida and Nematoda and parameters concerning the content, composition and quality of the organic matter of the soil substrates. **The communities of these animal groups became species- and individual-richer the higher the quality of these soil organic-matter parameters were.** Soil substrates with a correspondingly high content of organic matter also offer spatially and climatically advantageous habitat as well as most likely also a higher nutrient-resource supply. The reactions of individual collembolan species were dependent upon the species group: native species mostly followed this general trend of a positive reaction to the nutrient supply of the soils, while non-native species correlated negatively to these parameters. Only the species richness of Actinedida correlated negatively with soil pH, meaning that more species were recorded in soils with a lower pH value. Among the abiotic factors, particularly soil texture showed the lowest influence on animal community parameters.

The results concerning an impact of human activities on the soil fauna were not persistent throughout all animal groups, study years or faunistic parameters. Correspondingly, anthropogenic impacts were often "cryptic" within the total data and superimposed by high data variability. **Precise statistical procedures could nonetheless definitively prove a significant human influence on the studied soil fauna.** This influence is primarily due to a trampling effect, since in the studied areas neither human waste nor other forms of contamination are permitted and most likely are also not present.

At the level of the taxonomical major groups, human presence primarily influenced total abundances. Both the variance analyses and partially the covariance analyses could show that **the densities of all major animal groups (with exception of Actinedida) were significantly lower in areas influenced by human activities.** These effects could, however, not be observed when the individual major taxa were combined to even higher taxonomical/ecological groups. This indicates that the reactions of individual animal groups were taxon specific and not cumulative among the entire soil fauna. No general anthropogenic impact on species richness could be ascertained, even though in single years significantly reduced species numbers could be determined for the Collembola (in 2011) and Oribatida (2010) in the anthropogenically influenced areas.

The covariance analyses could further show a strong interaction between anthropogenic influence and the degree of vegetational cover. Human activity more strongly negatively influenced the densities in areas with middle levels of vegetational cover. **Where vegetation cover was only sporadic, human activities had stronger impacts than in areas where no or much vegetation existed.** This interaction was strongest among the Collembola, Actinedida, Oribatida and partly also the Nematoda. This is especially noteworthy, since in Antarctic habitats generally only larger aggregations of closed vegetation are legally protected, either as designated Antarctic Specially Protected Areas (ASPAs) or as "no-go" areas (prohibiting human access) in the Visitor Site Guidelines of the respective excursion site.

The anthropogenic impacts on individual species were variable. Some species were negatively influenced by increasing anthropogenic pressure (lower abundances), while other species were even positively influenced (higher abundances). The analyses further revealed for a number of species significant interactions between anthropogenic impact and the degree of vegetational cover, with significantly stronger anthropogenic impacts (whether positive or negative) at medium to high levels of vegetational cover. When all soil-animal groups are considered together, then **35% of the species showed either a positive or negative reaction to human activities**. When species are also considered, on which a human influence could be discerned in tendency even if statistically not significant, then **almost 2/3 of all recorded species are either negatively or positively impacted**. This can be considered to be an **indication of changes in the soil food-web structure in anthropogenically influenced areas**. Since the species-poor soil-animal communities in Antarctica include practically no functional redundancy, the continual human influence can lead to large changes in the ecosystem functions of the soil organisms.

In ecosystems containing many diverse microhabitats, the species composition can be different in the different microhabitat. These small-scale differences between various local spots is one of the main sources of biodiversity (local ß-diversity). It is conceivable that tourists transport soil substrates in the profiles of their boots or equipment and thereby also transfer soil animals from microhabitat to microhabitat, thus changing the biodiversity of the local microhabitats. However, for none of the studied animal groups could a human influence on their total ß-diversity be detected. On the other hand, the PERMANOVA analyses revealed a highly significant interaction between locality and human impact in the ß-diversity of the Actinedida and Tardigrada faunas. This indicates that a human-caused reduction in the ß-diversity of these animal groups can be confirmed, however only in some localities. An analysis of the data of specific localities showed a reduction in Actinedida and Tardigrada ß-diversity in the anthropogenically influenced areas of about 40% of the investigated localities.

Even though the results concerning an anthropogenic impact were not consistent throughout all animal groups, years or locations, **the total of all results reveals important faunistic changes, which can be attributed to a human influence**. Furthermore, many of the studied locations are populated by large penguin and seal colonies during the Antarctic summer, which obviously also have a large impact on the soils and soil fauna. All anthropogenic impacts revealed in the present study are therefore stronger in the intensively visited excursion sites and, especially, are above and beyond that caused by wildlife.

Through the results obtained in the present study, specific **recommendations** for a better protection of the sensitive Antarctic ecosystems from human impacts could be derived. These concern firstly the **biosecurity measures against the transfer and introduction of non-native soil organisms. Improvements in the education of Antarctic visitors on the necessity and use of these measures as well as in the control of the proper implantation are necessary.** This includes an **intensification of their use** between Subantarctic and Antarctic areas as well as after visiting sites already harboring high numbers of non-native species, such as Deception Island or Neko Harbour. Furthermore, **specific microhabitats must be more strongly protected**, for instance by an expansion of areas closed for visitors (i.e., “no-go” areas in the respective Visitor Site Guidelines) to include areas with initial or sporadic vegetation as well as around the vicinity of meltstreams (= areas of soil organic-matter collection and higher soil moistures). To prevent the further dispersal of non-native species in the future, it is

fundamentally necessary that the areas which tourists may visit be constrained. For this, a **"positive list"** is recommended, outside of which touristic visits should be generally prohibited. In addition, the establishment of an international, **long-term soil biological monitoring program** is proposed. Only through such a program can the understanding of the long-term human impacts on areas with strong touristic pressure as well as a monitoring of the success and improvement of biosecurity measures be achieved.