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Abstract. The EDEN-ISS is a greenhouse project at the Neumayer Station III in Antarctica. For the first time, this greenhouse supplied the station with fresh food and enabled research regarding sustainable and autonomous food production from Earth to Space. To investigate the plants' impact on the crew (biophilia), a debriefing, questionnaires, and behavioral observation were used. The results show that the crew was satisfied with the consumption of fresh vegetables, which are usually not available in Antarctica. All (9 of 9 crew members) also agreed on the positive psychological and physiological impact of the plants on their well-being. The investigation will be repeated with the next crew of the Neumayer Station III and will also be proposed for comparison at stations like Concordia.

Keywords: Human Factors · Human-systems integration · Space mission · Habitability · Psychology · Isolation plants · Interaction · Biophilia

1 Summary

In isolation, far away from the natural human conditions and Nature itself [1, 2] people may suffer from asthenia and depression.

This effect has emerged in many isolation conditions, being experienced by astronauts inside the International Space Station (ISS), prisoners, military personnel in submarines, as well as scientists at Antarctic stations, but also in more common conditions such as in nursing homes or prisons [3]. As explained in the concept of biophilia the interaction with plants appears to have a positive effect on motivation and performance; however, further research is needed to demonstrate its relationship with performance in long-duration isolation [4–6].

For these reasons, Human Factors and psychological studies of the effects of a greenhouse on the psychological well-being of crews living and working in isolation are extremely relevant.

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From December 2017 to February 2019, a group of ten scientists has been living at the Neumayer Station III (NMIII) in Antarctica surrounded by ice and isolated from the normal variety of life forms. During the mission, the crew built and tested the EDEN ISS greenhouse of the German Aerospace Center (DLR). For the first time, this greenhouse supplied the station with fresh food and enabled research regarding sustainable and autonomous food production from Earth to Space [7–9].

Various instruments were applied during the mission to investigate whether in isolation, interaction with plants might have a positive impact from a nutritional and psychological perspective, increasing performance and safety as in the Biophilia perspective [12]:

1. The "Human Factors debriefing" as a guided group discussion
2. Questionnaires:
   2.1 Robert Koch Institute Food Frequency Questionnaire
   2.2 POMS (Profile of Mood States)
   2.3 Dedicated questionnaire on the interaction with the plants [10]
3. Observation (e.g. interviews, recording of time spent in the greenhouse).

Meaningful instruments were the analysis of individual items from the questionnaire, interviews, and group discussions. In the questionnaire specifically, 7 of 7 subjects stated that they were satisfied with the consumption of raw vegetables. Moreover, everyone rated as "quite a lot" at least one of the positive effects of the plants listed. Finally, in the group discussion, the crew unanimously (9 of 9) agreed on the positive psychological and physiological impact of the plants on their well-being.

The investigation will be repeated with the next crew of the Neumayer Station III and will also be proposed at stations like Concordia in order to have a comparison crew without a greenhouse.

The aim of this paper is to present the results of the EDEN ISS investigation on the impact of interaction with plants during long-term missions on the mood of the crew members, on their performance, and generally on crew cohesion from a Human Factors perspective.

2 Introduction

The relevance of the connection between Nature and humans has been the topic of much research found in the literature, in particular from the 1960s when it was associated with the term 'biophilia' [11]. Biophilia refers to the desire for a (re)connection with natural life and natural systems[1] [12].

The healing power of a connection with Nature was established in the 1980s with a study comparing the recovery rates of patients with and without a view of Nature [13]. In the 1990s, experiments showed an increase in productivity when building occupants were connected through biophilic design [14].

[1] We should be genetically predisposed to prefer certain types of Nature and natural scenery, specifically the savanna (6. Savanna Hypothesis, 1986)

During the same period, architecture groups started to apply a biophilic approach, confirming the correlation between improved environmental quality and worker productivity [15]. While the financial gains due to productivity improvements were considered significant, productivity was identified as a placeholder for health and well-being, which have an even broader impact. In Space and Antarctica as well as in other extreme, dangerous, and isolated environments, where a person's productivity and reliability may impact the safety of human lives, the concept of biophilia may be of great importance [13].

3 EDEN ISS

The ability to grow food and other essential resources for humans through biological processes is a major aspect for Space missions, as it helps to:

- decrease the resupply mass currently required [16];
- allows astronauts to travel further and stay longer in Space [17];
- increases human safety, performance, and well-being as a result of biophilia [8, 9, 18].

In this context, DLR with decided in 2011 to develop a project together with a consortium of partners: the EDEN ISS (Evolution and Design of Environmentally-closed Nutrition-sources) greenhouse project [19].

EDEN ISS aims to develop and test plant cultivation systems in isolation in terms of:

- technologies and processes for ISS, planetary habitats, Earth application
- study of microbial behavior and countermeasures
- research of the physical and psychological impact, including oxygen production; enrichment of the diet with fresh food; and psychological effects on safety, performance, and well-being.

In the context of this project, the EDEN consortium has developed the Space-analog Mobile Test Facility (MTF), a Bio-regenerative Life Support System (BLSS) for Space and Earth application, which has been tested at the German Neumayer Station III in Antarctica [16] (Figs. 1, 2 and 3).

Fig. 1. EDEN laboratory at the DLR Institute of Space Systems in Bremen

Fig. 2. The MTF with in the background the Neumayer Station III in Antarctica (© DLR)

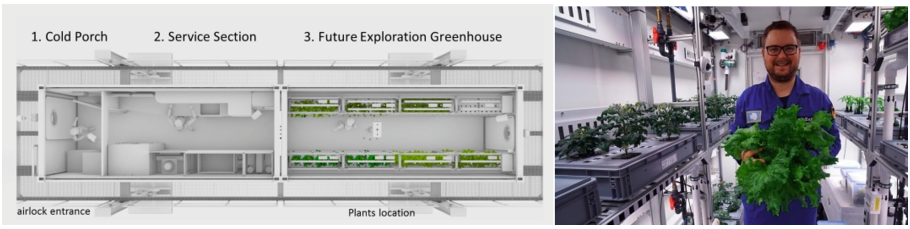

Fig. 3. The MTF 3D structure on the left and the inside of the greenhouse on the right (© DLR)

The MTF It is composed of 2 connected containers and contains: the Cold Porch (airlock entrance from the outside (−35 °C) to the inside (+20 °C)), the Service Section (laboratory for controlling, processing, and testing the plants), and the Greenhouse (aeroponic cultivation of 13 m^2 in shelves and trays associated with the bio-detection and decontamination system that ensures food quality and safety) [20]. (© Liquifier).

3.1 Project Challenges

The Greenhouse MTF was first built and tested in Bremen, Germany, and then transported by truck to Bremerhaven and loaded onto the Polarstern research vessel. After four weeks of travel to Cape Town, South Africa, it was loaded with equipment and traveled for ten days to the vicinity of the Neumayer Station III on an icebreaker vessel. Finally, it was loaded onto a sled and pulled for two hours over the ice by a PistenBully to the Neumayer III station, where it was raised by a crane onto its elevated platform (Fig. 4).

Fig. 4. EDEN ISS container transportation sequence

In order to be transported, the MTF had to be able to face complex system capabilities and logistics to be settled in Antarctica, such as: restricted access to Antarctic stations only during five months per year via aircraft; extremely warm (equatorial regions) and cold (Antarctic) zones traversed during the journey; fulfillment of the Container Safety Convention (CSC) requirements; shipment transportation dynamics (location of sensitive electronics in order to deal with significant vibration and shock loads, cranes, exposure to humidity, …).

3.2 Successful Achievement

Finally, the EDEN ISS was shipped to Antarctica and assembled there in January 2018, 400 m south of the Neumayer Station III. From the station it can be reached on foot along a secured trail with a railing, which assures safe passage, particularly in the dark winter or during a whiteout. After the greenhouse had been assembled and all the equipment and all the systems had been tested, the greenhouse went fully productive. After about half a year, it was producing a harvest of 7–8 kg per week (Fig. 5).

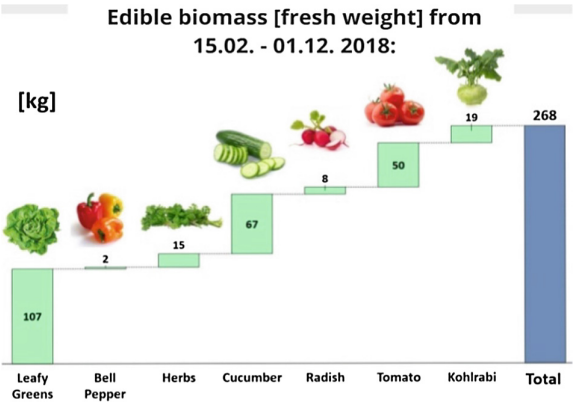

Fig. 5. EDEN ISS harvest 15 Feb.–1 Sep. 2018

4 Analysis of the Impact of Plants on the EDEN ISS Crew

To analyze the impact of plants in terms of fresh food production and consumption on performance and well-being, different tools were selected to be used by the Neumayer Station III 2017–2018 crew during the year of isolation in conjunction with the test of EDEN-ISS (Fig. 6):

1. The “Human Factors debriefing” as a guided group discussion about the crew’s human factors interaction with the plants. The goal was to collect in an open manner collective ideas/opinions; weaknesses/strengths/problems experienced and solutions found; and lessons learned during the mission regarding interaction with the plants from the perspective of the crew.

2. Questionnaires:
   2.1 Robert Koch Institute Food Frequency Questionnaire
   2.2 POMS (Profile of Mood States) for assessing the changes in morale the crew might exhibit while consuming fresh food.
   2.3 Dedicated questions on the interaction with the plants developed on the basis of previous investigations [10] to assess the wishes and needs of the participants regarding interaction with plants as well as the frequency, quality, and number of individual activities with the greenhouse and the plants.
3. Behavioral observation and interviews, including a record of the amount of time spent in the greenhouse by the crew, to identify the impact of the plants on the mood and performance of the people who used the greenhouse often versus those who used it less often. Final interviews were conducted after the end of the mission.

Fig. 6. Neumayer Station III team 2018

These tools aimed to assess the effects of the interaction with plants during long-term missions on the mood of the crew members, on their performance, and generally on crew cohesion from a psychological and Human Factors perspective (Fig. 7).

Fig. 7. The crew in October 2018, after ¾ of the mission, performing the Debriefing. It is interesting to note the longer beards like at the end of some long-duration Space missions.

The planning of the experiment started in 2015. In order to acquire comparison data, the investigation was also planned to be performed with the winter crew 2016–2017. The times selected for the data collection were discussed with the consortium of partners to identify the main investigation events and their interactions with the crew (Fig. 13).

Of the six proposed iterations, only three sets were approved by the consortium and after the ethical review: one before the mission and two (in June and October) during the mission. The time frame for the investigation was selected to be during the period of full vegetable production and outside possible highlights or important events that might influence the data collection on interaction with the plants (Fig. 8).

Crew:

Crew 2016–2017 without greenhouse -> control and comparison data
Crew 2018 with greenhouse

Time Schedule:

- Before the mission, as reference baseline data -> 10 October
- Middle of the mission -> 10 June
- End of the mission -> 10 October

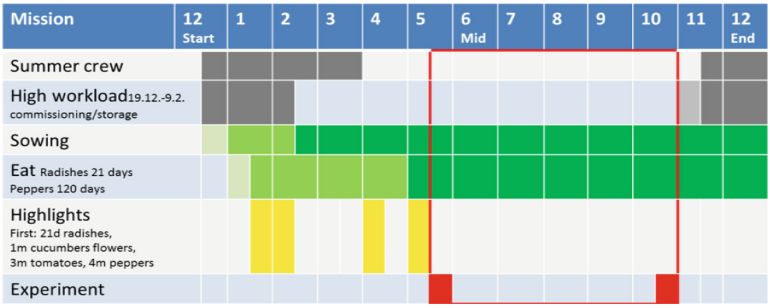

Fig. 8. Parameters for the selection of the time frame for performing the investigation.

4.1 Problems Encountered and Solutions

Some difficulties were encountered in the data collection, but solutions were found and adopted. These included, in particular: The investigations were performed only by crew 2018 during the mission in June and October. All the crew members had contact with the plants at least as fresh vegetables for food consumption. All the crew members were free to work or interact with the plants in the greenhouse. In order to enable comparison with a crew without interaction with plants, the investigation will also be proposed to the Concordia Station Crew 2020 (Table 1).

Table 1. Problems and solutions during the investigation

Problem	Cause	Solutions
Missing Crew 2016–2017 data collection without greenhouse -> control and comparison data	The crew was not informed. Prior to the mission, no crew member had been clearly identified as the person who would coordinate the investigation	Data collection performed on: - Crew 2019 - Concordia Crew 2020 (without interaction with plants)

(*continued*)

Table 1. (*continued*)

Problem	Cause	Solutions
Missing Crew 2018 baseline data	General difficulties collecting data before and after the mission as well as lack of a time schedule with open access to all the consortium members where they could implement the tasks	Data collection on: - Crew 2018 post-mission meeting with interviews
In the POMS, the items were not filled out completely	As in each questionnaire, a few questions had not been answered, the data could only be compared at the level of individual question items; a standardized factors analysis was not possible	- Explanation of the importance of filling out all the items - Sensibilization of the crew regarding the importance of data collection

4.2 Analysis of the Results

Meaningful instruments were the analysis of individual items from the questionnaire, interviews, and group discussions. On the food frequency questionnaire, in particular, 7 of 7 subjects stated that they were satisfied with the consumption of raw vegetables. Moreover, on the plants interactions questionnaire everyone rated as "quite a lot" at least one of the positive effects of the plants listed. Finally, in the group discussion, the crew unanimously (9 of 9) agreed on the positive psychological and physiological impact of the plants on their well-being.

Table 2. Debriefing main results of Crew 2018

Factor	Strength/Weakness	Vote	Description of most voted matters	Impact
Psychological	+	9/9	Fresh vegetables to eat	Well-being
Psychological	+	8/9	Natural colors	Well-being
Psychological	+	8/9	Observing, living, growing	Well-being
Physiological	+	9/9	Fresh vegetables, valuable nutrition	Well-being
Operational	−	8/9	Frequent system malfunctions	Performance
Operational	−	8/9	Alarm sounds at NMIII too frequent and annoying	Well-being
Operational	−	6/9	Cameras make the greenhouse less comfortable to relax in	Well-being
Operational	−	6/9	Too much lettuce/leafy greens	Performance
Socio-Cultural	−	7/9	Interaction with plants limited to only a few people (except consummation)	Well-being

Breakdown of the results:

1. The "Human Factors debriefing" was performed in October 2018.

As a result of the guided discussion, the crew reported that the positive impact on their well-being was the most important element of their interaction with the plants. Moreover, also other values were described such as: "relaxing", "living things", nice "smell". Also elements that need improvements were described such as: "the variety of herbs", "variability", "partly overripe", "it would be great to have it closer", "too far" (Table 2).

The psychological factor, in particular, was the factor associated most with interaction with the plants compared to the physiological, operational, socio-cultural, and environmental factors. As for the impact on safety, performance, and well-being, the latter was the one most frequently selected (Fig. 9).

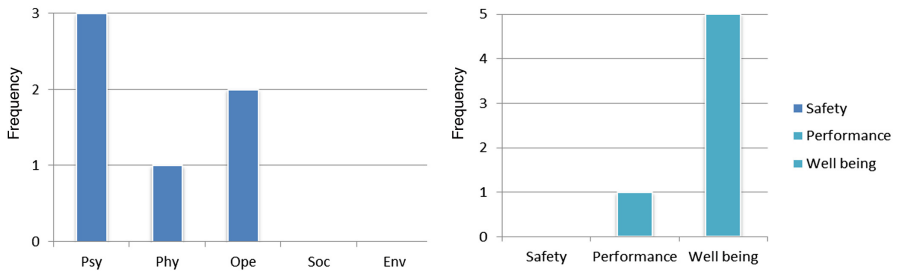

Fig. 9. Debriefing results showing the effect of interaction with plants.

1. Questionnaire

The Robert Koch Institute Food Frequency Questionnaire showed that in July as well as in October, all the subjects were satisfied with the consumption of fresh vegetables. The consumption of fresh vegetables is normally not possible during such missions. Here, it was already possible two months after the start of the mission and until the end of the mission after 14 months (Fig. 10).

The POMS factors analysis can only be performed after the collection of data from the next investigations because only 2 subjects of 10 fill in completed the questionnaire 2 times. Considering the strength of the feelings selected by the subjects ("a lot" weighted 0,5 & "extremely" weighted 1), it appears that the crew had the tendency to select lower feelings strength at the start of the mission and higher ones at the end of the mission (Fig. 11), however this tendency need to be confirmed with more subjects.

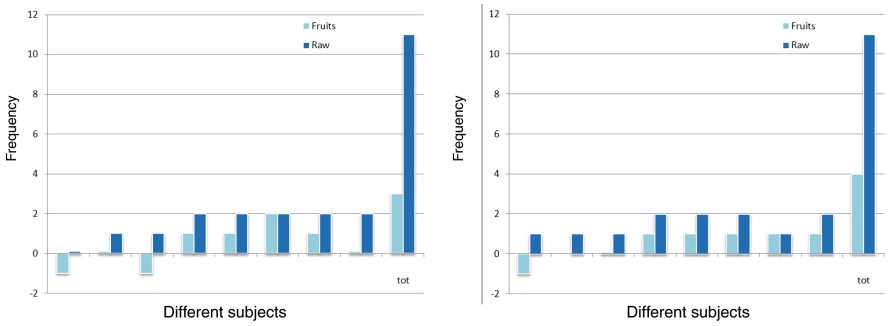

Fig. 10. Questionnaires results in June 2018 (left) and October 2018 (right) compare the level of satisfaction of the crew with the supply of the raw vegetables (provided only by the greenhouse system) in comparison with other food like fruits that need to be stored for long time(e.g. frozen).

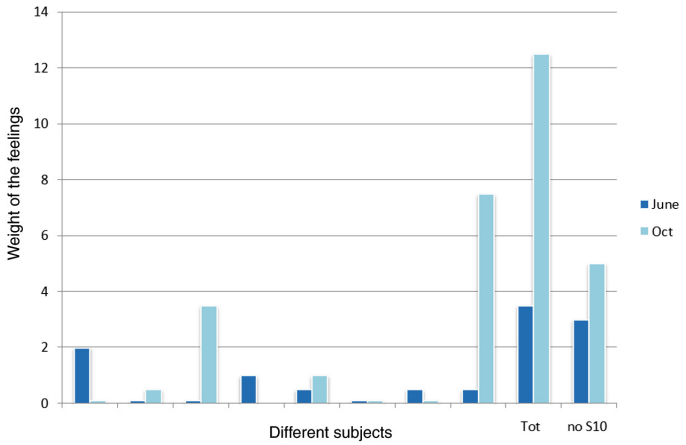

Fig. 11. Weight of the feeling selected on the POMS questionnaire on June and October 2018.

The dedicated questionnaire on the interaction with the plants required the crew members to evaluate whether the plants may have a recreational and nutritive value as well whether the interaction with the plants may positively impact their well-being, their motivation as well as crew relations. The results show that both in June 2018 and October 2018, the majority of the crew considered the nutritive value as well the impact on their well-being very important (Fig. 12). This confirms both the results of the debriefing and those of the Robert Koch Institute Food Frequency Questionnaire.

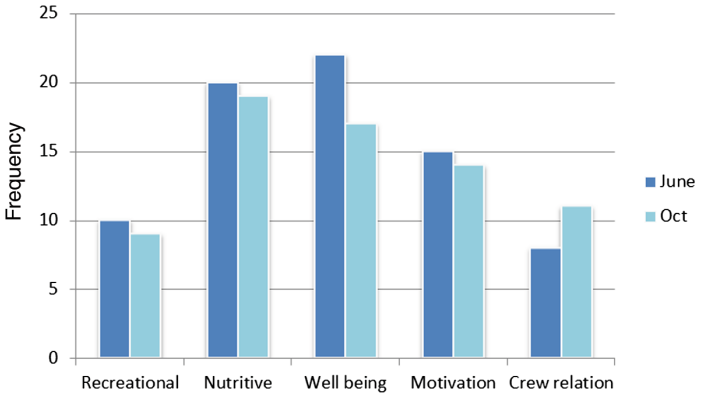

Fig. 12. Evaluation of the factors of impact on the interaction with plants.

Fig. 13. EDEN ISS partners

5 Conclusion

The EDEN ISS project is the first European bio-regenerative system tested in Antarctica. Although the cost of designing, deploying, and running Antarctic hydroponic facilities presently outweighs their return in terms of psychological and nutritional benefit, they make an important contribution to the advancement of international research on bio-regenerative systems both for the exploration of the Universe and for Earth applications [21].

Particularly, during the Crew 2018 mission, the psychological impact of the plants on their well-being was assessed as positive by all crew members as also foreseen by the biophilia concept.

The investigation will be repeated with the next crew of the Neumayer Station III and will also be proposed at stations like Concordia in order to have a comparison crew without a greenhouse.

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