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ORIGINAL PAPER

The social fabric of citizen science—drivers for long-term engagement in the German butterfly monitoring scheme

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Abstract

Insect conservation needs sound information on species distribution trends. Developing this evidence relies—in practice—on long-term engagement of volunteers who observe and record species over large spatial and temporal scales. Many biodiversity monitoring schemes, including those for insects, are highly dependent on conservation-based citizen science programs with a long-term continuity. As these schemes are built entirely on good will, the nature of social relations and networks is pivotal to success. We assess the working mechanism of a monitoring scheme that is citizen-based as a case study. The German Butterfly Monitoring Scheme (hereafter TMD for "Tagfalter-Monitoring Deutschland") operates, as many other citizen science monitoring schemes, through an overarching national network of regional subnetworks of volunteers and a central scientific coordination. Using a questionnaire survey paired with a visual social network assessment, we investigate how participants interact within these networks and assess their motivations to engage. We characterise the functionality of this social network based on mechanism of coordination and participation, flows of information and knowledge exchange among recorders, regional and central coordinators, academic scientists and institutions. By analyzing the interactions, we show how the social network facilitates and ensures various communication modes and thereby fosters long-term engagement, stability and growth of the scheme. We identify the central role of project coordination and the importance of social relations within citizen-based monitoring programs for engagement and personal satisfaction. Based on our empirical study, we derive a set of recommendations for establishing and maintaining successful volunteer networks in insect citizen-based monitoring programs.

Keywords Social network analysis · Insect conservation · Citizen science · Biodiversity monitoring · Motivation · Butterflies

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Introduction

Globally, the loss of biodiversity is progressing at an alarming rate (Pereira et al. 2012), which also holds true for species diversity (as indicated through red lists) as well as for the biomass of insects (Hallmann et al. 2017). These losses are not only of concern for conservation, but may also have severe economic implications, as can be exemplified through the loss of pollinators and their services (Potts et al. 2016). The study of Hallmann et al. (2017), combined with other long term research about insect declines, led to the development of concrete goals formulated by German government to halt the decline of insects in Germany and to establish a national biodiversity monitoring Centre. Biodiversity monitoring schemes provide the baseline to assess the success of both nationally and internationally agreed conservation targets, such as the aichi biodiversity targets 2011–2020 under the strategic plan for biodiversity and the sustainable development goals 2015 (Schmeller et al. 2009). The power of monitoring programs originates from the support by volunteers that gather large amounts of data over time and across geographic scales (Devictor et al. 2010), including information from private and residential land (Cooper et al. 2007). These highly valuable data about the status of biodiversity cannot be obtained otherwise and even official reporting depends on this, such as the European Butterfly Indicator for grasslands (Van Swaay et al. 2016). In fact, more than 80% of biodiversity data are provided by volunteers (Chandler et al. 2017). Monitoring generally requires long-term commitment by the participants and a fixed protocol for standardization and comparability of the data gathered. This can be challenging as monitoring of e.g. fixed transects and strict protocols can be demanding and laborious, and this may affect the motivation of participants. Thus, for monitoring schemes it is of vital importance to understand the structures and functioning of successful programs and to understand the motivations of the volunteers involved in these schemes and programs (Roy et al. 2012b; Tulloch et al. 2013).

We assume, that social networks are crucial for the success of monitoring schemes. More specifically, we hypothesize that the intensive and non-hierarchical exchange of information taking place in the program leads to long term commitment and engagement in the scheme. This very generic assumption was the basis for the collection of basic data for this study. To date, only few studies have investigated the power of social network dynamics and the processes that drive the continuity of these programs in relation to the people involved (Quarto et al. 2010; Tulloch et al. 2013). Successful projects have been reported to be predominantly characterized by locally appropriate and adaptive volunteer community structures, with functional network coordination and established mechanisms that facilitate information flow (Pollock and Whitelaw 2005). Functional networks enable both interactive online communication and face-to-face interactions (Gallo and Waitt 2011) and allow for collaborations, identified as constant interaction of participants with scientists and other volunteers as part of their learning experience (Freitag and Pfeffer 2013).

In the context of our study, we ask how the social network, i.e. a group of people involved in the citizen-based monitoring program, is composed. We seek this understanding to understand the functioning of the schemes and to inform mechanisms that foster long term engagement. As case study we investigate the social network of the German Butterfly Monitoring Scheme to address the following research questions:

What are the characteristics and motivations of actors involved in the TMD?

What are the most important communication instruments and means of engagement?

How can supporting network relations and structures be characterized?

Based on our qualitative and quantitative analyses, we identify motivations and structures for long term engagement and develop a set of pointers how to foster the social fabric of networks to achieve successful joint working in citizen-based monitoring programs.

Background and methodological concepts

The German butterfly monitoring scheme

The German butterfly monitoring scheme (hereafter TMD for "**T**agfalter-**M**onitoring **D**eutschland") is a countrywide monitoring scheme in Germany, established in 2005. The TMD provides a central foundation for the analysis of biodiversity patterns and for developing the role of butterflies as indicators for the state of biodiversity at the regional, national and European scale (Kühn et al. 2008). Over the last 13 years, more than 400 active volunteers support the scheme in every year. Participants of the TMD continuously collect data on butterfly species and their abundances on over 500 fixed transects throughout Germany with weekly to bi-weekly visits from April to September. So far, more than 2 million records have been obtained. The obtained data sets are analysed and combined with other monitoring data to address conservation questions in the context of climate and biodiversity research (Devictor et al. 2012; Settele et al. 2008), to review measures at the science-policy interface (Henle et al. 2013), and to contribute to national and international assessments (Kovács-Hostyánszki et al. 2017; Settele et al. 2015). The scheme has also been a model case to study the impact of communication and public relations in citizen science programs, to assess the advantages and shortcomings of volunteer- based data as well as to understand the socio-demographics characteristics of volunteers (Kühn et al. 2008). The TMD is comprised of many actors with many different professional and educational backgrounds. When starting the engagement in the scheme, some of the volunteers were novices in butterfly observations and identification. Others brought their long-term expertise in butterfly taxonomy and ecology into the scheme. All of the participants work in close collaboration with regional coordinators (n = 58) who are distributed throughout Germany and who share their expertise in species identification and transect methods with the volunteers. The regional coordinators also organize field trips and arrange meetings for the participants. In addition to the regional coordinators, state coordinators for each German federal state (n = 16) are responsible for assistance regarding data management and data quality check (identification errors checks e.g. through plausibility testing). Both, state and regional coordinators are also volunteers, often with a background in biological and environmental sciences. The scheme is supported by a core team of seven scientists from the Helmholtz Centre for Environmental Research—UFZ that coordinate the scheme in cooperation with the German Society for the Conservation of Butterflies and Moths (GfS = "Gesellschaft für Schmetterlingsschutz") and with the support of online platform *science4you* (link to platform via data entry portal @ http://www.tagfalter-monitoring.de). Several online media tools are established to inform the volunteers and the public about the program (see: http://www.facebook.com/tmdufz/, https://twitter.com/TagfalterD). The scientific coordination team is highly experienced in butterfly conservation biology, global change research, project management as well as data management, and data visualization. The central coordination team oversees the program and takes over responsibility for database maintenance, public relations, and scientific analysis of the data. Further the team supervises interactions with and among participants. With more than 10 years of experiences as a conservation-oriented program run by citizens, the TMD provides an ideal setting to unravel the complexity of the social fabric of a citizen-based program and to deepen the understanding about the impact of involvement in such a program. In this study, we apply the concepts of social network analysis using a questionnaire survey paired with a visual network assessment with a representative subset of TMD participants to objectively describe, characterize and analyze network relationships.

Empirical approach

Fundamental for social networks analyses (SNA) are three components: a network of (a) different actors with (b) certain characteristics, such as age, gender, motivations and roles in the network, and (c) the relationships between the actors in the network (Emirbayer and Goodwin 1994). Actors can be described as discrete individuals, corporate, or collective social units (e.g. people, subgroups, organizations), whereas relations or network interactions denote the linkages between numerous actors via social ties (relationships), that are characterized by behavioral interactions (e.g. communication, affection, advice), formal relations (e.g. authority) or personal relationships (e.g. kindship or descent) (Wasserman and Faust 1994). We define social networks as a specific set of linkages among actors, with the additional property that the characteristics of these linkages as a whole may be used to interpret the social behavior of the actors involved (Mitchell 1969). Based on this fairly general and abstract definition, network researchers use a differentiated set of research tools to investigate not only how network structures promote or constrain social action and perception (Diaz-Bone 2007), but also how actors use their network relations to realize their own objectives (Emirbayer and Goodwin 1994). Thus, social networks are specific networks based on the assumption of the importance of relationships among interacting units whereas actors and their actions are considered as interdependent rather than independent (Wasserman and Faust 1994). In order to capture the different aspects of a network, a growing number of SNA studies are based on mixed methods that integrate different kinds of knowledge, e.g. knowledge emerging from a classical SNA with knowledge from stakeholders on the relations between actors or the actors themselves (Beilin et al. 2013; Borg et al. 2015; Dominguez and Hollstein 2014; Prell et al. 2009). Small (2011) classifies mixed method studies into mixed data–collection studies and mixed data–analysis studies which can be combined as well. Mixed data–collection studies are those based on at least two kinds of data or two means of collecting them. Mixed data–analysis studies are those that, regardless of the number of data sources, either employ more than one analytical technique or cross techniques and types of data (such as using regression to analyze interview transcripts) (Small 2011). In order to understand the motivations of the citizen scientists to participate in the TMD citizen science programs and to address the questions posed in the introduction, we use a mixed method approach outlined in the following, which allows us to understand the types of actors that are involved, their motivations for participation and the structures that they are embedded in.

Data collection

For our study, we conducted a survey that involved a questionnaire and an assessment of social networks. The questionnaire (see appendix) consisted a set of questions concerning demographic information about the respondents and about the duration of involvement in the TMD (numbers in years). Further questions related to the level of participation, the importance of interaction and communication as well as changes of personal knowledge and skills over time (Table 1). Finally, we asked the participants to report on the motivations for current engagement in the program and ask to provide information for challenges and potential barriers that may affect current and future involvement in the program. Our questionnaire is completely based on self-reported data. The gathering of self-reported data is a core field in all social sciences and has been widely investigated and tested for its validity and reliability (Jupp 2006). The methodology is also widely applied in clinical psychology and well assessed regarding its advantages and disadvantages (Demetriou et al. 2015). Generally, accurate self-reported data is provided when the conditions of anonymity and lack of fear of reprisal/ penalization are met and the questions are formulated in an understandable way (Brener

Table 1 Summary of information obtained from the questionnaire

Categories	Questions	Units
Demographic parameter	Sex	Selection
	Year of birth	Year
	Age	Number
	Occupation	Description
	Profession	Classifications provided
Support gained from the TMD Network over time (at the beginning of engagement and today)	Assistance for species identification	Likert scale
	Assistance for the establishment of transect	Likert scale
	Importance of the exchange of scientific information	Likert scale
	Importance of the exchange of personal information	Likert scale
Importance of participation within the TMD over time (at the beginning of engagement and today)	Defining research question	Likert scale
	Data analysis	Likert scale
	Presenting findings in talks/interviews	Likert scale
	Supporting others to present findings	Likert scale
	Publishing findings in scientific journals	Likert scale
Importance of communication measures (past/current)	Annual report	Likert scale
	Usage of pictures in reports and for posters with credits to the producer	Likert scale
Knowledge gain over time (at the beginning of the engagement and today)	Taxonomy (species identification)	Likert scale
	Scientific literacy	Likert scale
	Ecological and biological understanding about butterflies	Likert scale
	Nature conservation	Likert scale
	Science-Policy relationship	Likert scale
	Environmental knowledge	Likert scale
	Environmental behavior	Likert scale
	Nature experience	Likert scale
Motivation	Describe your motivation to stay engaged in this program	Open question
Improvements	Formulate suggestions to make the program better	Open question
Experiences	Time of engagement in program	Year
	Duration of engagement	Year

et al. 2003). We offered several ways (situations) to fill in the survey to address potential situational effects on the accuracy of the self-reported data. The survey could be completed during the workshop in a separated room with single tables and chairs or otherwise at home in a more familiar setting. Despite this opportunity to choose the environment, all participants favored the option to fill in the questionnaire during the workshop. Cognitive issues such as understanding the questions or recounting the memory to answer the questions correctly were also considered as important when applying the self-reporting data collection survey. Prior to the actual data collection, the study as well as the questionnaire was explained in the panel and each question in the questionnaire was step by step explained. Further, two assistants were available throughout the workshop to assist with the questionnaire.

In a second step, we used network maps and asked the respondent to draw his or her own network concerning communication linkages in the TMD context. Participants were asked to distinguish between frequent (more than once a month) or less frequent communication (less than once a month) as a means for the qualitative and quantitative measures of the communication. Also, participants provided qualitative information about the formats of exchange and characterised the type of actors concerning their role, e.g. as butterfly recorder, central coordinator and regional or state coordinator, as well as their contacts outside the TMD network. Again, the procedure was explained stepwise in the panel, was performed in a calm setting and two assistants were available for support.

The complete data collection took place during the annual convention of the network in February 2015 that coincided with the 10th anniversary of the program. These annual meetings for all members of the program, both butterfly enthusiasts and researchers, are important regular events to exchange and celebrate the achievements of previous field seasons and the monitoring results, as well as to enable feedback and social interaction.

Data analysis

For data analysis, we first digitalized the information provided on the networks by the participants. All information were transferred to an excel sheet. The information derived from the participants such as information's on attributes, roles in the network, types of exchange with others and motivations to take part were anonymized. Missing data (e.g. actors ID) and encoded data (e.g. with initials) were received and/or confirmed for correctness by the TMD scientific coordinator. Incomplete data were removed from the final data set. Based on the final set of information, the network data was analyzed using social network analysis metrics. For this, we used the SNA software VisuaLyzer™ (http://socioworks.com/productsall/visualyzer/) to visualize the network and to calculated quantitative measures of "degree centrality" and "betweenness centrality" for the actors in the network (Wasserman and Faust 1994). Degree centrality is the count of an actor's direct links with other actors. Betweenness centrality is the measure of how often an actor is found on the shortest path between two other actors. This is generally seen as a measure of control, since actors with high betweenness centrality are in a position to control what flows between other actors in the network (Hanneman and Riddle 2005; Krebs 2004). In order to check for statistical differences for the provided information depending on multivariate factors, we performed a permutational Multivariate Analysis of Variance (MANOVA). We used the *adonis* function, available from the R package *vegan* (Oksanen et al. 2016), to determine (1) if the self-reported data on the contribution to the monitoring vary significantly across gender and age, and (2) if a participant's gender and/or age are factors that affect answers provided. The function *adonis* partitions the sums of squares of a multivariate data set, and is therefore directly analogous to a MANOVA (Anderson 2001; McArdle and Anderson 2001) The analysis is not based on original data, but on distance matrices. Through random permutations of the responses among the participants, the algorithm detects whether there are associations between participants and the given responses. Depending on the defined predictor variables and tests, whether these associations are significantly different from what would be expected by chance. Our analysis was based on 999 permutations, using the Euclidean distances of the differences in scores in the questionnaire data of the before-and-after data, using age and gender as well as their interaction as predictive variables. To check for influence of the respondents' age and/or gender on their motivations for participation in the program, we ran an analogous analysis based on Gower's distances (Gower 1971) of the respondent's motivations as factorial variables. For both analyses, the total sample set had to be reduced to 50 out of 62, due to missing values in the complete dataset.

Results

Characteristics of the sampled actors involved in the TMD

Out of the total number of active participants of the TMD (n = 445, in September 2015), a total of 132 volunteers (30%) participated in the annual convention in February 2015. From these, 62 participants followed our invitation to draw networks and to fill in the questionnaire (i.e. 47% of meeting participants and 14% of the overall number of volunteers). Importantly, many (one-third) of the central, regional and state coordinators took part of the event. About 60% of the respondents in our surveys were female, while the overall TMD gender ratio is slightly skewed to the opposite with 43% female and 57% male participants. In general, among all 445 TMD participants in 2015, female volunteers are more often involved in the actual observing and recording of butterflies (66%) whereas male participants are more central in the roles as coordinators (regional coordination: 56% male, federal state coordination: 100% male, national coordination: 71% male). This picture was also reflected in our survey with women more often involved as butterfly recorders and less often in coordination roles. The survey respondents came from across Germany, representing 15 out of 16 federal states. While we have no overall information about the average age of TMD participants in the TMD at that time, a previous survey in 2006 established that most respondents were between 40 and 69 years old (Kühn et al. 2008). For our survey, the average age was 55 years, while the youngest participant was 13 and the oldest 76 years old. One-third of the participants of the TMD is engaged in monitoring butterflies for more than 10 years and committed right from the start of the TMD. In our survey, the duration of engagement of the respondents varied from 1 to 9 years with an average of 7 years involvement for women and 8 years for men. The actors involved in the network differentiate between internal actors that have assigned roles within the program such as butterfly-recorders and coordinators and external actor that are not directly part of the TMD but connected to the program. Unexpectedly, the respondents revealed a large group of important actors in their own networks that are not formally involved in the TMD. This category consists of friends and family members of the TMD volunteers, representatives of government agencies, natural history museums and non-governmental organizations (NGO). The online platform "Lepiforum" (http://www.lepiforum.de) was identified as an important actor by different respondents. The online platform offers assistance in the identification of butterflies, and while it links to the TMD, it is not formally associated with the central coordination. The network actor roles were therefore grouped as internal actors (a) volunteer recorders, (b) regional or state coordinators, (c) central coordinator, and for external actors (d) individual external actors, (e) government/NGO actors and as (f) the Lepiforum online Butterfly ID information platform.

Self-reported motivations for participation in the program

The question about motivations was answered by 60 participants. Multiple responses were possible and envisioned with the application of an open question, resulting in 149 statements (motives) for participating the program. Based on an inductive analysis of the qualitative data about motivation, we identified four major categories of motivations for participation in the TMD program (Table 2). First, participants expressed an overall desire for improvements of personal skills and knowledge through the involvement in the TMD. The acquisition of knowledge on butterfly species and their biology and ecology as well as species identification skills and the ability to discover new species were named as major motivational reasons. Second, participants considered the personal enjoyment of nature, specifically the accomplishments of relaxation and personal well-being while being out in nature as important reasons to take part of the program. Third, a strong driver for engagement identified is the opportunity to act and influence nature conservation, reflected in answers such as "because it is important to influence policy and society" or "my contribution is the assistance to the conservation of species". Fourth, participants appreciated the opportunity for social interaction, such as spending time with like-minded people and the communication of personal as well as professional information among other participants. This included also the exchange of information with the central coordination team, regional and state coordinators and other participants, as well as establishing and caring for friendships made through the program. The responses

Table 2 Categories of motivations and their percentages (times referred in the questionnaire based on the total number of statements n = 149) identified as response to an open question by members of the TMD (n = 60)

Categories of motivations	Communicated as	Citation (examples)	Percentage
Desire for improvement of personal skills	Improvement of species ID skills Acquisition of personal knowledge about butterflies	"from time to time I find new things", "increase of personal knowledge", "expanding knowledge", "to learn something", "discovery of new species", "data are getting better from year to year"	25.5
Personal enjoyment of nature	Relaxation Personal enjoyment Personal well-being	"enjoyment of nature", " a great reason to spend time outdoors", "connection to nature", "motivation to go outside", "the exercise outdoors", "I very much love nature", "it is great fun"	14.4
Acting and influencing nature conservation	Sharing expertise/knowledge Raising awareness Supporting butterfly conservation Expression of influence Action to make a change	"impact of climate change on butterfly populations", "importance to influence policy and society", "my own contribution to an environmental project", "data gain more power", "assistance to the conservation of species", "long term observations", "to support research"	26.2
Seeking and building relationships	Establishment of friendships Maintenance of friendships	"meeting like-minded people", "contacts among participants", "exchange with others", "opportunities to exchange with others", "the established friendships"	8.2

Table 3 Results of MANOVA analysis on association of age and gender with categories of motivation (from Table 2) to contribute to the monitoring scheme, using the self-reported answers

Predictor	Df	SS	Mean SS	F	R²	p
On categories of motivation						
Sex	1	0.1251	0	0.99143	0,020	0.441
Age	1	0.2554	0	2.02461	0,041	0.197
Sex × age	1	0.0336	0	0.26637	0,005	0.712
Residuals	46	5.8022	0	–	0,933	–
	60	6.2162	–	–	1	–

All p-values > 0.05, indicate non-significant relationships on motivations were not depending on age, gender or their interaction, as shown by the MANOVA results (Table 3).

The questionnaire also identified challenges expressed for ongoing and future involvement. Again, 60 participants provided information on the challenges, resulting in a set of 68 statements (reasons) expressing challenges for future involvement. The most often stated challenges were lack of time (12 out of 68 statements referring to this reason) and the daily encounter to set priorities for volunteering and other daily tasks (11 out of 68). Further, the processes of data entry and the use of the technical infrastructure (11 out of 68) were mentioned as an ongoing challenge. Also age and health related issues and consequently physical constraints (7 out of 68) were put forward as arguments for a potential withdraw of the engagement. For a few participants the repetitiveness of the task or the lack of new or interesting species as well as the accessibility of the transect (4 out of 68) presented additional motivational issues.

As a key point that increases and maintains the involvement in the program, the participants identified (a) the ongoing assistance and training in species identification by experts, (b) continuing personal interactions with coordinators as well as (c) the establishment of activities that endorse stronger local political interest in the butterfly monitoring scheme and its results.

Improving personal skills during the monitoring scheme

The respondents reported that the involvement in the program increased individual skills including species identification, understanding data analysis and scientific literacy (Fig. 1). Considerable interest and knowledge in nature education and nature conservation existed for many respondents already from the beginning of their involvement, whereas scientific literacy, understanding of data analysis and understanding of the complexity of ecological processes markedly improved through the involvement (Fig. 1). The answers provided showed no significant dependency of age, gender or their interaction, as shown by the MANOVA results (Table 4).

Importance of communication instruments and engagement

The respondents reported that both forms of communication, personal and context-related, were important straight from the beginning of the involvement and this importance continued over time. Also, receiving the Annual Report (as special issues of the journal *Oedippus*; http://ebooks.pensoft.net/series.php?ser=1095) has been of high importance to the participants since the beginning. Participants stated

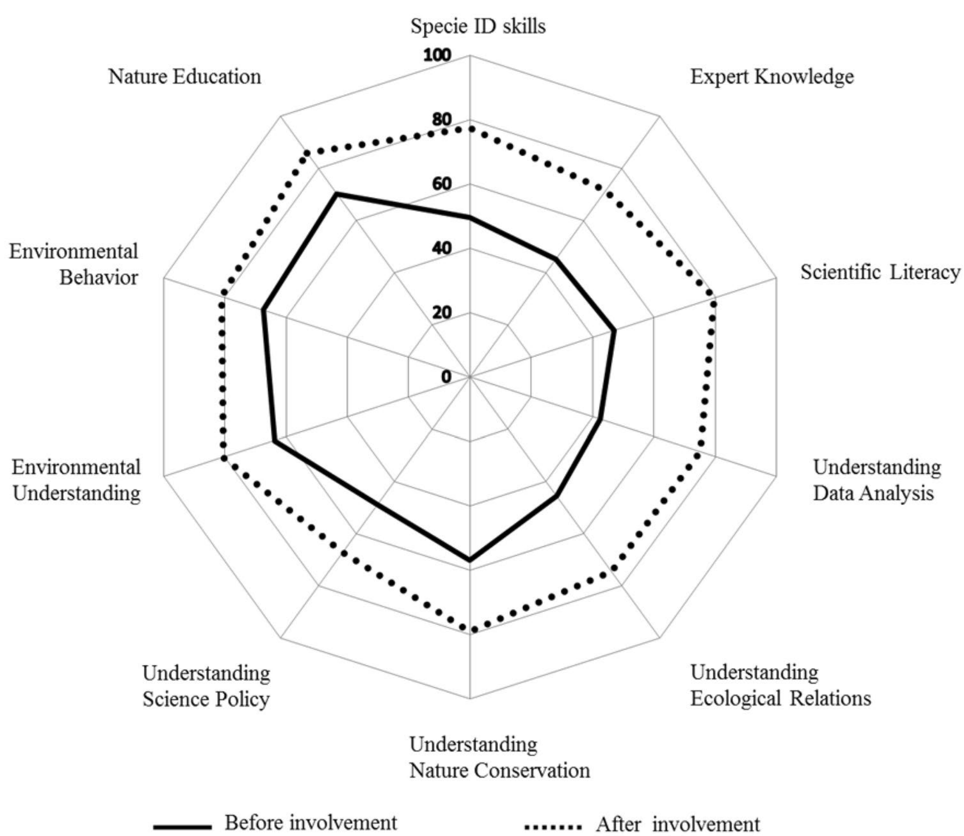

Fig. 1 Self-reported changes in knowledge and understanding by TMD participants before and after the involvement in the program

Table 4 Results of MANOVA analysis on association of age and gender with responses to contribute to the monitoring scheme, using the self-reported answers

Predictor	Df	SS	Mean SS	F	R^2	p
On responses						
Sex	1	14.32	14	0.703	0.015	0.636
Age	1	15.33	15	0.752	0.016	0.584
Sex × age	1	13.8	14	0.677	0.014	0.614
Residuals	46	936.55	20	–	0.956	–
	49	980	–	–	1	–

All p-values > 0.05, indicate non-significant relationships

increasing interests to participate in the publication of the findings from the TMD in scientific journal. This interest in using the data from the scheme as well as communicating the findings reflects an increasing understanding about the scientific values of the data obtained from the TMD. According to the respondents responses there was no actual desire to participate more in the identification of research question or data analysis over time (Fig. 2).

Again, we detected no significant dependency of age, gender or their interaction on the answers provided (Table 4).

Network structures

Most relations between actors are linked to information exchange in the TMD context. Here we differentiate between frequent, i.e. once a month or more often, and less frequent contacts. Those relations occurring frequently build "strong relations", those less frequent "weak relations". The respondents in our survey indicated that within the TMD there are network structures of both types of relations—weak as well as strong ones. These relations are built upon various forms of personal exchanges. Many respondents mentioned contact via emails and telephone calls as well as frequent face-to-face contacts in many cases. Personal communication also takes place during workshops, seminars, excursions, site visits or meetings with other butterfly-recorders and the state and regional coordinators. A special form of exchange takes place via the internet. A number of different online platforms were identified to be important for exchanges. With regards to positions of the actors in the network, the central TMD coordination (UFZ, GfS & science4you) fulfills a central role. Frequent direct contacts are made between the TMD coordination and many recorders, leading to strong relations (Fig. 3a). While the centrality indices have to be taken with care as our sample is just a fraction of the whole network, there are some

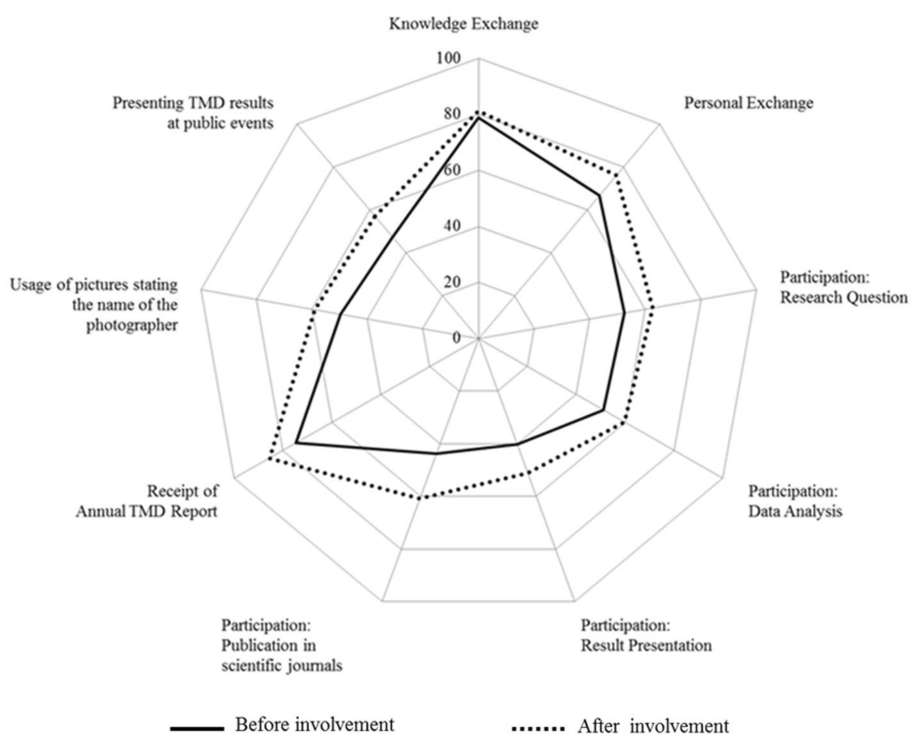

Fig. 2 Self-reported importance of communication and levels of participation before and after the involvement in the program

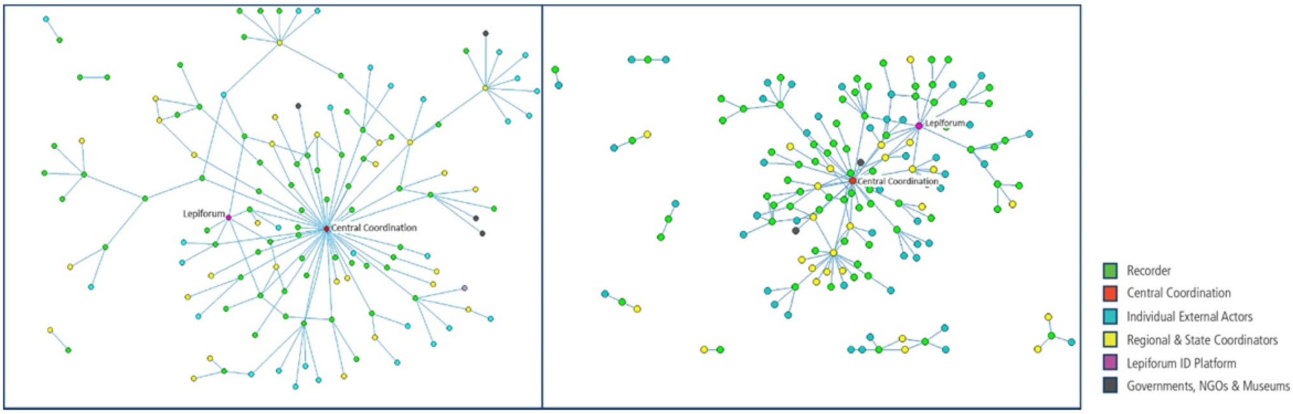

Fig. 3 Left: network structure for strong relations (frequent contact to the actors) with the Central Coordination (UFZ, GfS, s4y) and the Lepiforum (an ID platform playing a central role in the network) and right: with weak relations (less frequent contact to the actors) with the Central Coordination (UFZ, GfS, s4y) and the Lepiforum (an ID platform also playing a central role in the network)

important peculiarities. The importance of TMD coordination is reflected in the high degree centrality (17.5% compared to the average of 1.4%) and betweenness centrality (51.2% compared to the average of 1.4%). The centrality is also shown in the visualization of the network with strong relations (Fig. 3a). In addition, the Lepiforum online platform is identified as an important actor with comparatively high degrees of centrality (8.1% compared to the average of 1.4%) and betweenness centrality (22.0% compared to the average of 1.4%). Following the logic of voluntary coordination at a regional and state level, the assumption would be that the voluntary coordinators are next in the list of actors with high centrality, too. However, while there is one coordinator with rather high values (degree: 10.7; betweenness 16.6), other actors with above average degrees and betweenness are mostly other recorders, which might be dues to the small sample size, but also could indicate, that some recorders take part of the program in a relatively independent manner. However, none of the actors is left isolated within or rather beside the network and at least weak relations exist among all actors (Fig. 3b). Again, the central TMD coordination is of great centrality, indicated by the degree centrality of 30.8% compared to the average of 1.7% and a betweenness centrality of 82.5% compared to the average of 2.0%. These measures indicate that most network participants have a regular, while infrequent contact with the central coordination team. In contrast, the Lepiforum does not play a central role in the network of weak relations, with a degree centrality of 4.5% compared to the average of 1.7% and a betweenness centrality of 2.7% compared to the average of 2.0%. Similar to the network of strong relations the regional and state coordinators do not play a more central role than the recorders. The analysis also revealed that several actors exist that are not officially members of the TMD program (each participant is registered) but play a role in the network. Those external actors are from governments, NGOs, and museums, but also friends and family members were mentioned as actors to exchange information. In summary, comparing both networks of strong and weak relations, the TMD central coordination appears to be essential to maintain communication in the network and all actors share at least weak relations with the central coordination. Many also share strong relations. Importantly, also regional and state coordinators as well as external actors are part of both network types.

Discussion

The study demonstrates how different actors of a citizen-based monitoring program are embedded within a social network structure. The visualization of this structure with local recorders, regional and national coordinators, academic scientists and various institutions through social network analysis allowed the identification of the type and intensity of interactions among representative members of this program (Hauck et al. 2015; Herz et al. 2015; Schönhuth et al. 2014). The network analysis also highlighted the interpersonal connections among actors as well as the relations to collective actors such as organizations and institutions outside the citizen science program. The relations endorse both personal and content-related communications of various intensities. Importantly, the central coordination of the monitoring program plays a vital role (Bachinger et al. 2018; Calvet-Mir et al. 2015; Crona and Bodin 2006). Even after 10 years of running the program, the central coordination still matters immensely for communication to all involved network actors within the program. This is an important result, and highlights the significance of providing long-term resources for the employment of a coordination team to promote recruitment and long-term engagement of participants and as such stability and longevity of monitoring program that are based on citizen's engagement. Next to central coordination, peer support provides a strong social linkage, as identified by the many interactions between volunteer recorders among themselves and with regional coordinators (Beilin et al. 2013; Bodin and Crona 2009; Borg et al. 2015). When considering the design of citizen science networks, the pivotal need to respond to communication demands within the network should not be underestimated. If this communication task is left to voluntary regional coordinators only, however, they might easily become overwhelmed due to lack of capacity, and this would make the functioning of the program vulnerable (Lelong et al. 2016). Therefore, adequate incentive systems and ongoing central coordination are essential to relieve the burden of the volunteer regional coordinators. Personal motivations for participation are benefits such as learning and improving knowledge about science and scientific thinking (i.e. scientific literacy) (Bachinger et al. 2018; Hauck et al. 2015). Many volunteers participate in citizen science because of the individual enjoyment and the opportunity to engage in "real" science (Geoghegan et al. 2016; Kragh 2016). The network structure investigated and the embeddedness of the actors in the social network highlight the personal benefits beyond scientific discovery that are also drivers for the sustained development of a social network (Bodin and Crona 2009). We showed that personal enjoyment and social interactions were equally important to participation. Personal well-being achieved via the actual physical activity as well as through the establishment and maintenance of friendships were identified as highly beneficial by respondents, similar to other citizen science- initiatives (Geoghegan et al. 2016; Kragh 2016; Rotman et al. 2012; Roy et al. 2012a). Intense exchange processes among the actors with emails und phone calls are equally important as personal (face to face) contacts for exchange. Intensive exchange of information (communication) is expected to create relationships that can in turn sustain successful collaborations (Crona and Bodin 2006; Leach and Pelkey 2001; Prell et al. 2009) between the citizen scientists and other scientists. Each identified actor in the system fulfils a position and is in some way or another connected to other actors. Communication enables a closer connection between scientists and the public (van Vliet et al. 2014). Blogs, forums, or other contemporary social networking technologies are in place to communicate within and outside the community (Raddick et al. 2010, 2013). We also learned that networks of groups of people that interact with each other do not exist or evolve in isolation but rather develop through networked connections with network actors in a dynamic way (Pallett and Chilvers 2015). The development of a user-driven platform in co-existence with the monitoring scheme stands exemplary for the dynamics of networks of the people. We wish to raise attention to some caveats that might be associated with our investigation. Our analysis is based on a subset of participants from the TMD. We performed the social network analysis with just over an tenth of the total number of participants of the TMD. Thus, the analysed network and the findings are not comprehensive for the whole TMD. We ensured that our subsample represents the overall governance structure of the TMD (e.g. gender ratio, age structures, positions fulfilled such as regional coordinator and so on) and ensured that all the components of the potential system of the network are included in the analysis. Yet, the risk of sample bias remains.

Based on the experience of the TMD and our findings from the social network analysis and the questionnaire we gained critical insights into the motivation of volunteers to become involved and to stay engaged. Only with the understanding of the motivations of future participants and the knowledge of structures and conditions that are required to maintain participation, designs for citizen science projects can be developed successfully (Geoghegan et al. 2016; Kragh 2016; Kühn et al. 2008; Land-Zandstra et al. 2016). As such we can derive the following recommendations for recruitment and retainement of recorders in citizens-based monitoring programs:

- Organizational management and coordination: A fully functioning, central coordination is vital to manage and maintain knowledge exchange and communication within the network alongside regional coordinators. A central coordination is needed to take on the main administrative burdens as well as to alleviate more general communication work from regional coordinators. The experience also from other monitoring schemes, e.g. for birds, shows, that coordination and communication can push the professionality and longevity of programs (Sullivan et al. 2014).
- Different actor roles in the citizen science network: Regional coordinators are important for assistance in species identification and local data validation and curation, if applicable. Most often they also act as facilitators for communication, and in many cases their role is to develop trust. This in turns enhances local participation.
- Diversity of communication formats: Involvement of a diversity of citizens requires the full range of communication formats to be employed. While much of the communication can be accomplished electronically, personal face-to-face contact and even postal letters are still important (van Vliet et al. 2014).
- Diversity of motivations: participation is driven by a diversity of motives, such as gaining personal skills and knowledge as well as gaining personal enjoyment of nature and spending time with like-minded people. These types of motivations need consideration during

the design of a citizen science program to attract and maintain involvement of participants.
- Self-organization: facilitation of self-organization of active knowledge and personal exchange both within and outside the citizen science network is an important element to allow for enhancing both scientific literacy and scientific rigor and thereby personal empowerment of participants as well as their social interaction.

In summary, the commission of adequate resources to staff and funding allocated to coordination and volunteer management is key to successfully run a citizen science program. These coordination roles can be taken on by actors within and outside science institutions, and require important management and interpersonal skills. Overall, our study demonstrates how the social fabric serves as glue for citizens-based monitoring schemes. The social network qualities of citizen science programs and the role of central and regional coordinators are vital to achieve both scientific success and overall enjoyment—foundations for the long-term engagement of volunteers and thereby the longevity and success of citizen science monitoring schemes. Environmental citizen science is a highly valuable approach that contributes to the collection of biodiversity data (Schmeller et al. 2009). Under the consideration that knowledge about biodiversity remains in many places inadequate and with great gaps e.g. poor understanding about the taxa being present and absent as well as the geographical distributions of the taxa, environmental citizen-science has a great potential to solve some inherent biological data shortfalls, such as the so-called Linnean and Wallacean shortfalls (Hortal et al. 2015). Further, citizen science enables lifelong learning and the development of an attachment to places and objects through civic engagement (Aceves-Bueno et al. 2015). Both benefits, scientific as well as societal benefits, are best achieved in environmental citizen science when the program is well-designed, coordinated and well-managed. Based on our results, we show that understanding both the social network and the flows of personal and professional knowledge among and within participants of the network as well as the motivations is crucial for designing and performing these programs (Domroese and Johnson 2017). We conclude that facilitation of successful social network structures therefore needs to be anticipated in planning, recognized in funding programs. In addition, this needs to be incentivized also in career development for coordinators to allow for a thriving citizen science landscape. Patterns and processes of social networks in citizen science are crucial determinants to success. We therefore hope the social dimension of insect monitoring can be recognized as important area of research and conservation management.

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