MAX PLANCK INSTITUTE
OF ANIMAL BEHAVIOR

2017-2021

# REPORT TO THE SCIENTIFIC ADVISORY BOARD

**OUR VISION IS TO UNDERSTAND AND PREDICT ANIMAL DECISION-MAKING IN THE NATURAL WORLD.**

# MPI-AB IN NUMBERS 2017-2021

**28** BSc Students finished

**24** MSc Students finished

**10** Doctoral Students finished

**20**
animal taxa held at the Institute

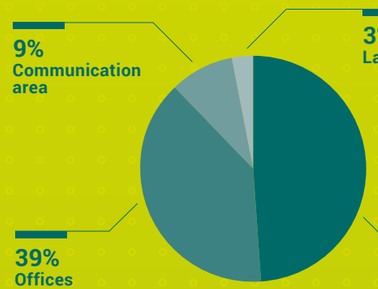
**474** peer-reviewed papers

**19**
children born

**14.7** million €
third-party funding granted

**56.8** million €
total Institute finances

## Space




**75** percent of publications open access

**3** Institute locations

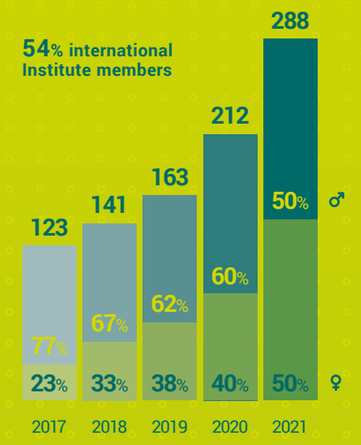
**3** selected Awards

**Alexander von Humboldt Professorship**
to Meg Crofoot
**Lagrange Prize** to Iain Couzin
**James Heineman Research Award**
to Andrea Flack

**selected Grants**

**Freigeist Fellowship** for Caroline Schuppli
**ERC Starting Grant** for Damien Farine
**3 Human Frontier Science Program Research Grants**
for Dina Dechmann, Ariana Strandburg-Peshkin and Alex Jordan

## People




**800**
participants in our international conferences

**248,875**
visits to our outreach activities

**96**
international scientists supported through our Welcome Office

# TABLE OF CONTENTS




# Dear members of our Scientific Advisory Board,

It is an extraordinary pleasure for me to introduce our new Max Planck Institute of Animal Behavior.

Born on the first of June 2019, the MPI-AB came into the world animated by a vision: to gain a predictive and quantitative understanding of animal decision-making in the natural world. I'm writing to thank you, the SAB, for helping deliver this vision. The members of the last SAB, who supported our concept of evolving from the MPI for Ornithology, have been nothing less than the midwives of our nascent Institute. We are immensely grateful that you supported our vision, and we hope—in the pages of this report—to introduce you to the science, staff, and spirit of MPI-AB.

We all predicted that the first year of life would hold surprises. But not even the best modelers among us could have predicted the shocks that were to come. The coronavirus pandemic emptied our offices, labs, and field sites from March 2020 (and continues to leave our team scattered well into 2021). But as the chaos of the pandemic unfurled, our infant institute showed strength and creativity well beyond its years. I am very proud of our team. They protected each other's health, they supported each other through unendurable isolation, they looked after their families at home—and they came together to figure out a new way of doing science.

Yet these measures also put a necessary end to in-person events, including the first SAB evaluation for the MPI-AB. It's too early to know when we can resume normal operations, but my co-Directors, Meg Crofoot, Iain Couzin, and I look forward to the time when we can welcome you personally to Konstanz and Radolfzell; to discover the scope of our research, meet our young scientists, and explore our infrastructure and developments. In the meantime, we hope that this report and our online event at the end of the year will convey the depth of our work and the spirit of our staff that, together, are our Institute's pride.

Pride is core to our family history—and that history is an indelible part of MPI-AB today. To understand the Institute, it's helpful to look beyond the reporting period, back to 2007, when I was appointed Director of the MPI for Ornithology in Radolfzell. At that time, the "Vogelwarte Radolfzell", as the institute was then called, still resided in the moated castle of Möggingen where it was founded in 1946. The internet was slow, rooms and workplaces were scarce, but the spirit of the two dozen staff was extraordinary: scientists, technicians, and (the barely existing) administrative unit were a small, conspiratorial community who identified fervently with the Institute. These employees, with their passion and commitment, provided the foundation from which the site flourished over the next 14 years—and they remain crucial to our success to this very day. Today, even though the number of employees has increased by an order of magnitude, the internet is (mostly) fast, and we have built and rented new labs, animal housing, and offices, it is still our employees who go above and beyond with their dedication and identification and thus make this Institute the very special place it is.

## WHAT HAVE BEEN THE MOST IMPORTANT DEVELOPMENTS IN THE LAST FOUR YEARS?

Before I talk about the foundation of the Institute, what this means for us, and where we want to go, I would like to talk about the new people who have powered our growth and development.

We are extremely fortunate to have Meg Crofoot, our third Director, who joined with the Institute's founding. The award of the highly prestigious Humboldt Professorship helps her to build the Department for the Ecology of Animal Societies. Focusing her research around the question of how animal societies emerge and function, and by concentrating on mammal species in the wild, Meg's work both complements and extends the work of Iain's Department and my own. Of particular importance are Meg's conceptual efforts to develop a common framework on the "sociome"—creating the means by which the interactions of animals at all group levels can be compared and interpreted—as well as her efforts to rescue field data from around the globe and form a collaborative network of researchers committed to standardizing. Her foresight will not only impact our Institute, it promises to advance the study of animal behavior at large.

In addition to Meg and the members of her Department, we have recruited three other young female scientists to our Institute—all of whom bring fresh ideas that boost MPI-AB research capacity. In 2017, Lucy Aplin was awarded one of the few and distinctly competitive open-topic Max Planck Research Groups,

and her Group has been an extremely productive part of our Institute since 2018. She explores the fascinating and often understudied impact that animal culture can have on cognitive evolution and thus local behavioral patterns in animal populations. Then in 2019, Serena Ding beat the international competition to win one of the Max Planck Research Groups advertised by our Institute, and has been building her Genes and Behavior Group in close collaboration with the University of Konstanz since the beginning of this year. Using a new high-throughput imaging system, she will conduct hundreds of behavioral experiments involving different *Caenorhabditis* strains simultaneously, analyze their collective behavior, and identify genes that influence the behavior of this ubiquitous animal group. Our Institute's second Max Planck Research Group was awarded to Caroline Schuppli, who also won a Freigeist grant from the Volkswagen Foundation. Similar to Lucy, Caroline is researching highly cognitively developed animals, but she goes one step further: she is studying the individual development of cognitive skills in wild orangutans—a species with the longest individual development of any animal. In addition to her fieldwork, the Suaq long-term dataset that Caroline is curating is the centerpiece of her work.

We have also formally reorganized our Departments by appointing our previous PIs as Group Leaders to give them the visibility and independence they deserve; you will therefore find in this report the dispatches of the three Directors and three Max Planck Research Group Leaders, but also those of eight Group Leaders, thus properly reflecting the diversity as well as the organization of our research. Less visible, but no less important, is our increase in Central Services staff. In our former incarnation as part of the MPI for Ornithology, many administrative tasks were carried out entirely or partially in Seewiesen. But these competencies have since been reallocated and employees hired to service our independent MPI-AB. The direct contact between researchers and professional staff has galvanized the community and improved efficiency—a testament to the resounding success of our new administration. The expansion also extends to Scientific Services, which includes animal caretakers and veterinarians who look after the welfare of our laboratory animals, and our innovative IT team who must provide secure and fast internet at three locations as well as the storage of huge amounts of data. To further advance technological development, but also to retain essential knowledge and skills at the Institute in the long term, plans are underway to develop the Advanced Research Technology (ART) Unit—a group of central scientists who support all MPI-AB researchers to develop and adopt emerging technologies and methods.

Our infrastructure and technology have also seen a huge boost in recent years. Our ICARUS antenna was launched to the ISS in 2018 and installed in a six-hour spacewalk. After some teething problems and expected adjustments, we are now receiving animal movement data from over 100 collaborative projects from every continent—ICARUS flies, unleashing unimaginable data in its wake. What ICARUS is to animal movements on a global scale, the quantitative methods developed by Dept Couzin are to animal behavior on a local scale. Markerless tracking and identification of individuals in large groups, behavioral classification, full control of the abiotic and biotic environment of animals with 'holographic' virtual reality (VR)—these are the technological breakthroughs driven by Iain and his team that bring us a big step closer to realizing our vision of understanding and predicting animal decision-making in the natural world. We are fully aware that the possibilities offered by this Institute are unique, which is why we naturally do not monopolize all developments, but rather publish them openly and freely, or make them available at cost price, in order to empower the global research community and the next generation of scientists.

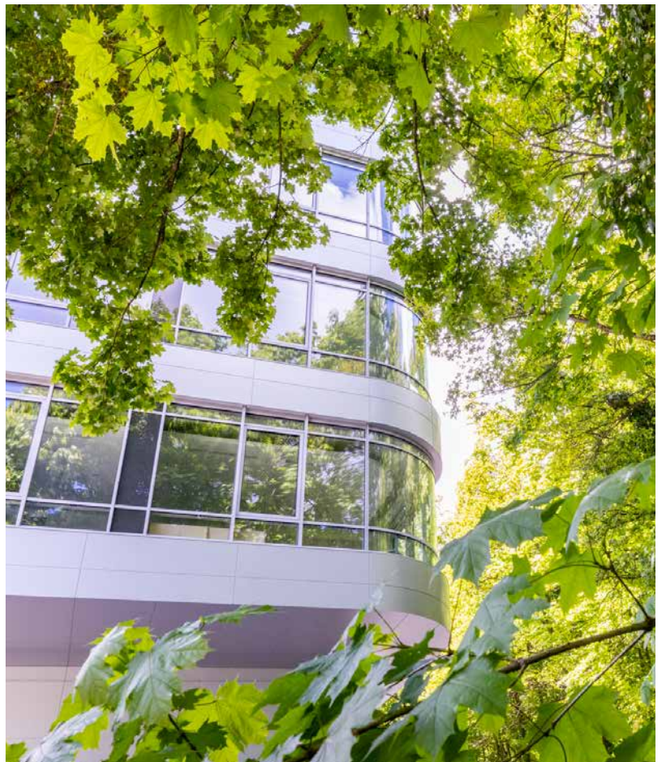
On our way to make Konstanz a center of modern behavioral biology, we have a powerful partner in the University of Konstanz. Not only are Iain and Meg full professors in the Department of Biology, but the University has also constructed a unique building: the Centre for Visual Computing of Collectives (VCC), which houses the world's largest ultra-high-resolution tracking facility for non-human animals, the "Imaging Hangar". In 2019, this partnership reached new heights when the university's Centre for the Advanced Study of Collective Behaviour (CASCB) was funded under the German Excellence Strategy. In CASCB, scientists from biology, social psychology, behavioral economics, physics, and computer science come together to jointly increase our understanding of collective phenomena through theoretically informed yet highly quantitative approaches in a vibrant and globally attractive hotspot for research. It's hard to imagine a better addition to this Konstanz hub for behavioral biology. To further strengthen this close partnership, our new Institute building, where all staff will be united under one roof, will be built on the campus of the University of Konstanz in six years' time.

## WHERE DO WE STAND AND WHERE DO WE WANT TO GO?

Now, turning to what all this growth in staff and infrastructure means. The foundation of the MPI-AB marks a turning point for the study of animal behavior. It attests to the place of behavior at the foundation of ecology, evolution, neurobiology, and genetics. All of these disciplines advance with input from biologists studying animal behavior at all levels of biological organization. In the past, animal behavior could only conduct sporadic observations of usually short duration and with low temporal and spatial resolution. This has changed through the advent of novel consumer technology and our own developments that can now be used to study the behavior of wild animals over a lifetime and in the highest resolution, heralding a new age in which behavior informs ecology and evolution.

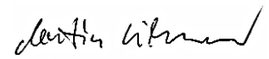
At our new Institute, we focus on key projects but also go into the breadth of animal behavior by supporting and supplying global databases that are essential for the development of this entire field. Furthermore, we are training a new generation of students in high-definition approaches that are crucial for advancing the field. We trust that our mission of using natural model systems combined with laboratory experiments and new technology is illuminating the trail for animal behavior scientists into the future. At the same time, we are convinced that animal behavior has real-life applications. Not only have we successfully received a range of patents, we also use our knowledge for conservation of animals in different settings around the globe. Importantly, we are expanding our citizen science network that is built on a 100-year tradition of working with volunteer bird banders internationally.

*Centre for Visual Computing of Collectives*



Despite the promises inherent in modern animal behavior, we acknowledge and temporarily accept important shortcomings of our approach. Most importantly, we are aware that the developments in the study of global animal movements, the study of collective behavior, and social evolution are currently not following a joint synthesis or overarching concept. The reason is that most developments are so new that it will take several years to build up the theoretical framework linking them. Furthermore, we have internal shortcomings, as the Departments and Groups are largely working in three locations and, throughout the past two years, personal communications have been very difficult. Moreover, fieldwork and lab work has been exceedingly difficult during the pandemic and prevented some progress at least in practical developments.

But if our long history has taught us anything, it is that we will continue striving to bring light to the study of animal behavior no matter the odds. Our earliest ancestor institute was founded in 1901. It survived the influenza pandemic of 1918 and narrowly missed total destruction in WWII. Out of the ashes of the war, it emerged, stronger, as the Vogelwarte Radolfzell, transforming again into the joint institute with Seewiesen in 1959, then finally the MPI-AB in 2019. Throughout this 120-year history, the Institute's lineage of scientists and staff have dared to trail-blaze the way to a deeper understanding of animals in the natural world. The Institute of today is driven by a mission of rigorous and open science; of mutual partnerships in the global community; of empowering the next generation; of diversity and inclusivity. But our ambitions are still growing. Our aim is nothing less than to be a standard-bearer for the study of animal behavior in the modern age. This is the start of our next 120 years. We thank you for joining us on our continuing adventure.



*Martin Wikelski*
*Managing Director*

# THE MAKING OF MPI-AB

SEP
**2017**

International Bio-Logging Symposium in Konstanz

MAY
**2018**

Inauguration of the Max Planck - Yale Center for Biodiversity Movement and Global Change

JUN
**2019**

Start of the new MPI of Animal Behavior

AUG
**2019**

Association for the Study of Animal Behaviour summer conference in Konstanz

JUL
**2020**

Moving of the Department for the Ecology of Animal Societies into the interim offices at Bücklestrasse

JAN
**2021**

Start of the MPRG Development and Evolution of Cognition, headed by Caroline Schuppli

MAY
**2021**

Moving of the Department of Collective Behavior to the new VCC building

JAN
**2018**

Start of the MPRG Cognitive and Cultural Ecology, headed by Lucy Aplin

JAN
**2019**

Start of the Cluster of Excellence "Centre for the Advanced Study of Collective Behaviour"

JUL
**2019**

Start of Meg Crofoot, heading the third Department for the Ecology of Animal Societies

SEP
**2020**

Official start of ICARUS

FEB
**2021**

Start of the MPRG Genes and Behaviour, headed by Serena Ding

**2027**

Moving into the new Institute building at the University campus

# MISSION

## 1. OUR VISION + OUR MISSION

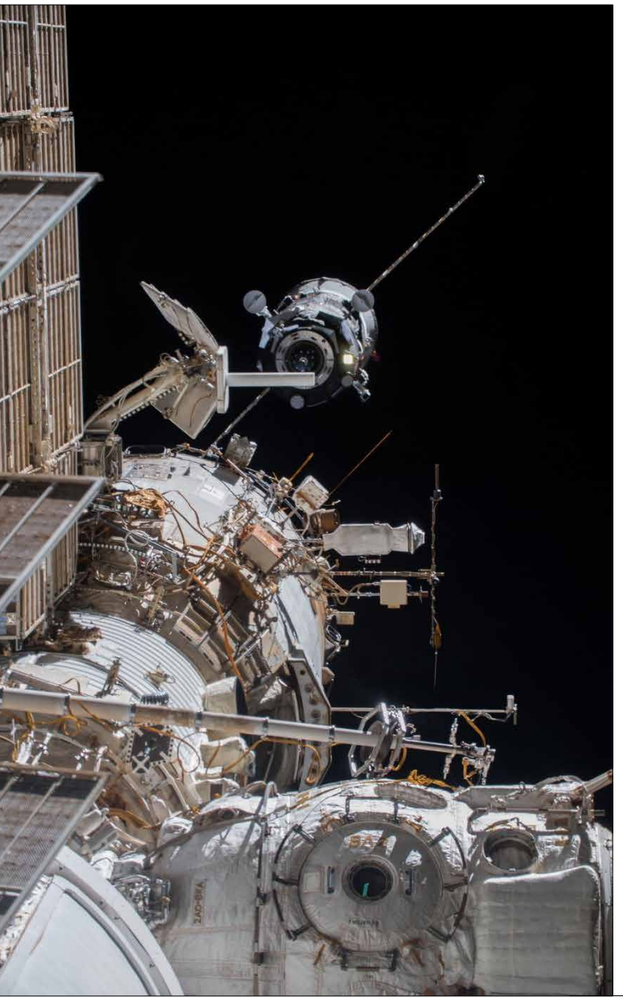
# OUR VISION

Our vision is to understand and predict animal decision-making in the natural world.

# OUR MISSION

By developing and applying emerging technological and analytical approaches, our mission is to reveal the drivers of behavior across temporal, spatial, organizational, and taxonomic scales.To take up this challenge in all its complexity, we bring together a diverse, interdisciplinary team to produce rigorous and reproducible science that is shared openly. In this way, we contribute positively to the global research community and provide scientific training to empower the next generation.We foster a supportive and inclusive work environment that promotes intellectual exchange and productive collaboration.


## BY DEVELOPING AND APPLYING EMERGING TECHNOLOGICAL AND ANALYTICAL APPROACHES, …



### Vocalization and localization

With international collaborators, we are using combined GPS, audio, and Inertial Measurement Unit (IMU) tracking collars to study how entire social groups of four mammalian species communicate and coordinate while on the move.
(Group Strandburg-Peshkin; page 62)

### Automated tracking

TRex, Tracktor, and DeepPoseKit are some examples of our open-source software. These tools enable automated tracking and identification of individuals within animal groups, as well as reconstruction of their body-posture using artificial intelligence and machine learning techniques.
(Dept. Couzin; page 32)

### ICARUS

The satellite-based animal monitoring system ICARUS allows researchers to explore the collective knowledge of animals on Earth. With the help of small transmitters, scientists can for the first time continuously record the behavioral and health data of small animals across geographic boundaries.
(Dept. Wikelski; page 70)

## … OUR MISSION IS TO REVEAL THE DRIVERS OF BEHAVIOR …

### Nutritional landscapes

Food determines where animals go. But the resolution at which food resources are mapped has yet to catch up with the high-res GPS data now available for animal movements. To link these scales, we are developing deep learning models to identify macronutrients in a suite of remotely sensed data, including hyperspectral imagery, thermal imagery, and LiDAR. (Dept. Crofoot; page 50)

### Animal-environmental interactions

By investigating animal-environmental interactions, we aim to integrate animal movement with habitat suitability and thus, to predict the direct future of species communities under climate change.
(Group Safi; page 100)

### Genetic basis

With our recent development in high throughput behavioral imaging and quantification methods, we aim to link behavioral variation to natural genetic variation in thousands of wild worm strains isolated worldwide. (Group Ding; page 116)

### Animal culture

Research in urban-living parrots has tracked a “bin-opening” innovation as it spread to form new “urban cultures”, demonstrating how social learning and culture can drive adaptive flexibility to new environments. (Group Aplin; page 108)

## … ACROSS TEMPORAL, SPATIAL, ORGANIZATIONAL, AND TAXONOMIC SCALES.

### Individuals over time (I)

For decades, researchers have been observing orangutans at Suaq Balimbing in Indonesia and compiling a treasure trove of field data on individuals. This database will pave the way for understanding how skills and abilities develop in individuals and, ultimately, the evolution of high-level cognition in great apes. (Group Schuppli; page 124)

### Individuals over time (II)

The common shrew is an animal with an uncommon ability: it shrinks its brain in winter and regrows it in spring. This remarkable wintering adaptation is a model for seasonal phenotypes of non-migrating animals, and opens a window into applied research on the regeneration of tissues, especially in the brain. (Group Dechmann; page 76)

### From lab to field

To bridge the quantitative gap between lab and field studies, we have pioneered methods for studying animals in their natural habitat, even in challenging environments. Low-cost and open-source, our machine-learning framework for analysing behavior can be applied to field settings anywhere, allowing rigorous, quantitative comparisons of behavioral repertoires across species and habitats. (Group Jordan; page 42)

### Female scientists

True to our core value of diversity, the MPI-AB has taken strides in achieving gender balance. The percentage of female scientists at the Institute increased during the last four years on all scientific levels, from Doctoral Students to Directors. (Personnel; page 166)

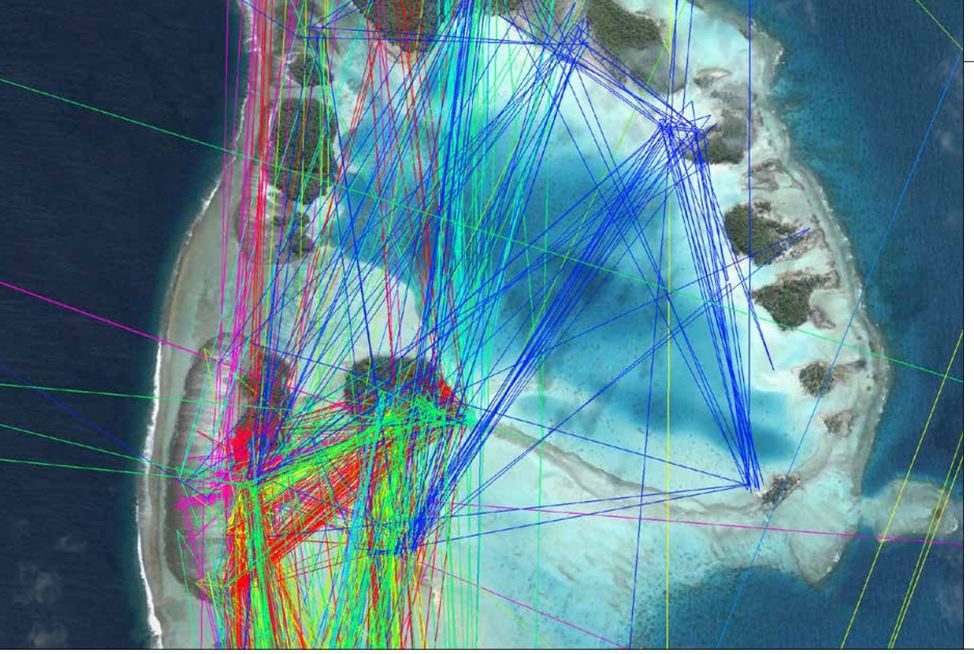
### International team

The MPI-AB is becoming a truly international institute. Our diverse staff, who come from 32 countries representing all continents, broaden our horizons beyond our local borders. Further, our collaborative partnerships with over a hundred institutes around the world extend our reach into the global scientific community. (Global collective; page 26)

### Gender equality

The MPI-AB is supported by a dedicated team, led by a Gender Equality Officer, that supports employees and drives progress towards equal opportunities goals. While there is an emphasis on female scientists, all genders are included in their focus. (Equal Opportunities; page 160)

## TO TAKE UP THIS CHALLENGE IN ALL ITS COMPLEXITY, WE BRING TOGETHER A DIVERSE, INTERDISCIPLINARY TEAM …



## Open access

MPG and MPI-AB are committed to full and free access to scientific results. Seventy-five percent of the 474 peer-reviewed journal articles published by MPI-AB scientists during the reporting period are open access. This includes our top 15 most cited publications. (Scientific outreach; page 140)

## Open code

In line with our commitment to publishing our code openly, we have built MoveApps: a no-code platform for the analysis of movement data. This toolbox brings movement ecologists in possession of data and in need of analytical tools together with people who have programming skills and the interest in providing time to extend the platform's capabilities. (Group Safi; page 100)

## Open data

Studying the behavior of animals by equipping them with tags places an ethical emphasis on the importance of sharing data openly. Our global database for animal movement and behavior—Movebank—publicly displays uploaded animal tracks and archives movement data long-term in its repository.
(Dept. Wikelski; page 70)

**… TO PRODUCE RIGOROUS AND REPRODUCIBLE SCIENCE THAT IS SHARED OPENLY.**





**IN THIS WAY, WE CONTRIBUTE POSITIVELY TO THE GLOBAL RESEARCH COMMUNITY AND PROVIDE SCIENTIFIC TRAINING TO EMPOWER THE NEXT GENERATION.**

## Teaching at the University of Konstanz

We are an active partner in teaching at U KN. Our most in-depth, but also most popular, offerings are the six-week Master's courses in which students gain theoretical background coupled with hands-on experience completing a research project.
(Career support; page 156)

## MaxCine

At MaxCine, our center for communication and exchange, empowering the next generation starts in school. Working by the motto "Out of school, into science", MaxCine inspires exchange between students and scientists on topics such as languages; animal behavior; ethics and sustainability; artificial intelligence; philosophy and art; culture and traditions. (Public engagement; page 162)

## IMPRS

Our graduate school—the IMPRS for Organismal Biology—was founded 12 years ago with U KN and the MPI for Ornithology. Ten MPI-AB Doctoral Students defended successfully in the reporting period and our IMPRS students contributed to more than 20% of our publications.
(Career support; page 157)

## WE FOSTER A SUPPORTIVE AND INCLUSIVE WORK ENVIRONMENT THAT PROMOTES INTELLECTUAL EXCHANGE AND PRODUCTIVE COLLABORATION.

### Scientific support

Science is a team effort and our Central Services are the foundation for future scientific breakthroughs. These include the animal caretakers, veterinarians, central scientists, technicians, computer scientists, science coordinators, and administrators of MPI-AB. Their support of our scientists is what cements our reputation not merely for research excellence—but also a culture of excellence. (Backbone; page 132)

### Welcome Office

We hope that our young and international Institute will become a beacon for scientists all over the world. With that aim in mind, our Welcome Office was created to support those scientists who come to Konstanz. Its mission to eliminate the barriers of relocating to a new city or country extends not only to scientists, but also to accompanying partners and children. (Equal opportunities; page 160)

### Scientific collaboration

In 2018, two former Postdocs from Depts. Couzin and Wikelski—Mate Nagy (physicist) and Andrea Flack (biologist)—cooperated on work that yielded breath-taking insights into collective migration of white storks. Their story provides an exemplar of what can happen when cross-disciplinary and -departmental collaborations are allowed to flourish with the help of time, chance, and the right environment.
(Group Flack; page 88)

# OUR GLOBAL COLLECTIVE

### North America

In 2018, the MPI-AB joined forces with Yale University. Combining our strengths in animal tracking with their prowess in spatial and environmental analysis, the Max Planck–Yale Center for Biodiversity Movement and Global Change is pushing the frontiers of animal ecology and biodiversity research.

### Central America

The Ecology of Animal Societies extends Meg Crofoot's longstanding research relationship in Panama. A project exploring tool use in capuchins living in Coiba National Park involves local undergrad students who provide field assistance and expertise on biodiversity surveys. At the same time, students build capacity in behavioral experiments, manuscript preparation, and education outreach.

### South America

Originally from Colombia, Adriana Maldonado-Chaparro joined MPI-AB as a Postdoc in 2016. Four years later, she returned to Colombia as a Professor at the Universidad del Rosario where she established a Max Planck Partner Group. With five years' support from the MPI-AB for a project on oilbirds, this partnership helps Maldonado-Chaparro to kickstart her group and international collaborations.


Partner institutions with a formalized cooperation agreement

### Europe

As a German-Russian mission, ICARUS has produced a partnership that is literally out of this world. The national space agencies from Russia (Roscosmos) and Germany (DLR) have joined forces with MPI-AB in a mutual mission to pioneer global animal tracking. In its first five months, ICARUS has generated 103 projects, 21 of which are in Russia.

### Asia

At the orangutan field site in the Suaq forest in Sumatra, Caroline Schuppli's Group works closely with the forest community. Local staff help maintain the Group's research projects and protect the forest's valuable resources by keeping illegal loggers at bay.

### Africa

To study the most abundant mammal in Africa, Dina Dechmann's Group has partnered with the Rwanda Wildlife Conservation Association. Rwandan collaborators tag and count bats, in turn benefiting from weekly tutorials, co-authorship, and joint grants with MPI-AB staff.

### Australia

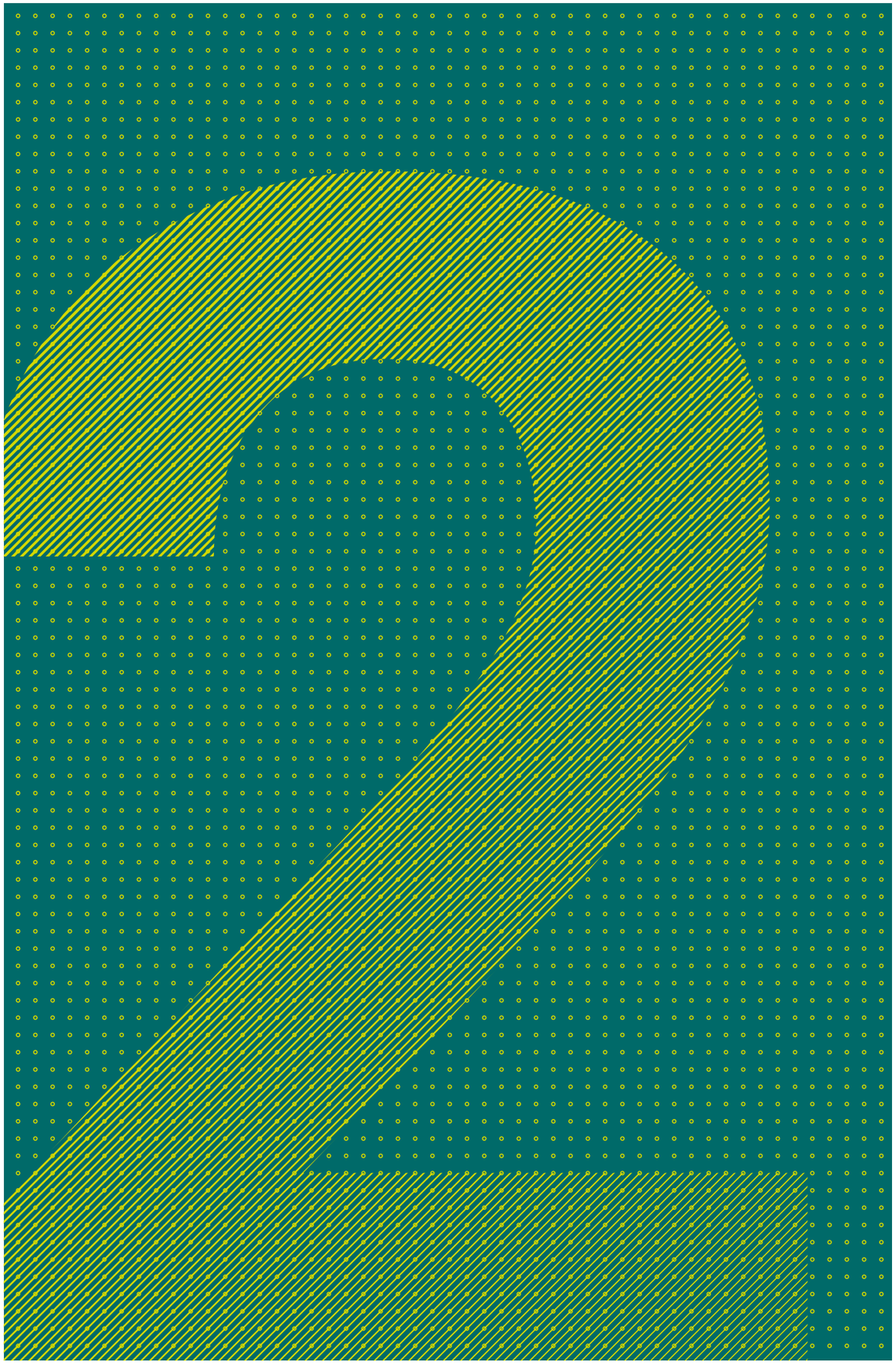
Lucy Aplin's Group have partnered with the University of Sydney and Taronga Zoo in Sydney to launch the BigCityBirds smartphone app. Harnessing the "many eyes" of citizen science is helping the Aplin Group study how birds respond to the opportunities and challenges of urban living.

**7** International scientific events organized

**32** Nationalities working at the MPI-AB

**15** Affiliated scientists in 7 different countries

Co-author institutions from **83** countries



# DEPARTMENTS AND GROUPS

## 2.1 Collective Behavior



## 2.2 Ecology of Animal Societies



## 2.3 Migration



## 2.4 Cognitive and Cultural Ecology



## 2.5 Genes and Behavior



## 2.6 Development and Evolution of Cognition

# DEPARTMENT COLLECTIVE BEHAVIOR

# DEPARTMENT COLLECTIVE BEHAVIOR

**DIRECTOR: IAIN D. COUZIN**

The Department of Collective Behavior aims to reveal fundamental principles that underlie collective behavior across scales of biological organization. Employing an integrated theoretical and experimental research program, we explore the functional properties of collectives as well as how, and why, they have evolved. Our work is characterized by a highly quantitative approach, such as the development and use of new imaging and virtual reality (VR) technologies that allow us to investigate behavior across scales. We employ numerical and analytical approaches in our development of theory (Figure II.1). This has allowed us to identify principles in common among what may initially appear to be disparate biological processes.

## Research achievements

Within this assessment period, our work has been published in leading scientific journals including *Nature, Science, PNAS, Nature Communications, Nature Methods, eLife,* and *Current Biology*. A principal focus has been to establish relationships that exist between individual intelligence, and the higher-order, collective computational capabilities of animal collectives.

### FROM INDIVIDUAL INTELLIGENCE TO THE CAPABILITIES OF COLLECTIVES

A key challenge faced by animals is to appropriately adjust their behavioral responses to changing environmental contexts, such as increased predation risk. The process by which individual organisms achieve effective context-dependent behavior, and how this is encoded in the brain, have been well studied. However, we know remarkably little about the corresponding aspects of collective information processing in animal groups. We discovered that risk is encoded as a collective property in fish schools, mediated via changing the structure (*edges*) of their network of interactions, as opposed to individuals (network *nodes*) altering how they respond to sensory cues (1). We also explored how social network structure can predict the life and death of honeybees (2), and how modularity in interaction networks causes information loss, but that this improves the accuracy of collective decisions (3).

In army ants, we found that the seemingly-collective "scaffolding" structures, formed from ants' bodies to aid others' transit across inclined surfaces, result from a proportional control mechanism mediated via individual-level error sensing and correction, with no communication among the ants. This minimal, robust algorithm may prove relevant for the design of self-healing materials (4).

In (5) we investigated collective maze solving by rats, revealing that synergistic advantages arise from a hierarchy of responses to social and asocial cues. We also employed our methodology, utilizing zebrafish, to study how mutations in 90 genes associated with human psychiatric illness specifically impact individual social response, and collective behavior (6). In addition, we applied this to the advanced global tracking of the Wikelski Department. Collaborating closely (co-first authors from each department in *Science*), we studied the collective migration of storks. As predicted by our theory (7-9) we found that a small number of birds lead migrations, while others exploit cheaper socially-facilitated information (10, 11).

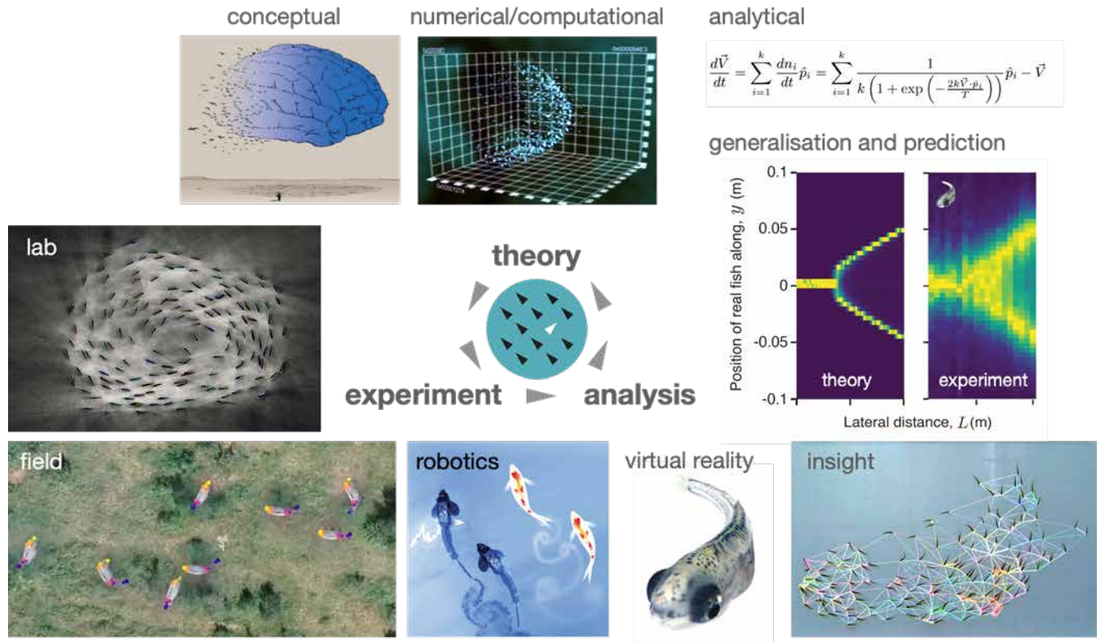



*Figure II.1 – An overview of the integrative approach employed in the Couzin Department. Theory offers an essential backbone to our research program. Whereas numerical simulations can capture system-specific details, analytical mathematical models provide a vital means to understand and to generalise our findings across systems; both prove invaluable for making testable predictions. Experimental work is often guided by our theoretical predictions, but can also be exploratory in nature. We conduct research on a wide range of systems in the laboratory (e.g., locusts, flies, ants, termites, bees, fish, birds, and rats) and the field (e.g., locusts, ants, fish, birds, zebra, primates), and have developed leading technologies for tracking as well as body posture and visual field reconstruction. In addition, we engineered new biomimetic robotic and 'holographic' virtual reality technologies, allowing us to investigate individual and collective sensing and decision-making in increasingly powerful ways. Analysis of the massive, multi-dimensional datasets generated by these new approaches combines elements from deep learning and probabilistic inference, allowing us to produce interpretable representations while readily scaling to tens-of-millions of observables. Together, our objective is to utilize these approaches to reveal the principles that underlie evolved computation across scales of biological organisation.*

It has long been suggested that schooling may allow fish to obtain hydrodynamic benefits, but a coherent biologically-plausible mechanism remained elusive. We developed bio-mimetic robotic fish to measure, directly, the power consumption associated with schooling (not possible for real or simulated systems). Doing so revealed a new rule—vortex phase matching—which we subsequently found real fish employ, via proprioception (requiring neither vision nor the lateral line), to save energy when schooling (12, 13).

### BUILDING TOOLS AND COMMUNITY

These studies required the development of new technologies for automated tracking and identification of unmarked individuals (TRex; 14), body-posture reconstruction (DeepPoseKit; 15), analytic tools for vast data sets (VAE-SNE; 16), bio-mimetic robotics (12, 13), and 'holographic' virtual reality (VR) for animals (FreemoVR, 17).

All are open-source, enabling access to these technologies for next-generation, replicable behavioral studies.

We also worked extensively to build a vibrant, collaborative research community in Konstanz. In July 2021 we moved into our new €32M building designed for the interdisciplinary study of collective behavior. In addition, Couzin led a further successful €30.5M application to establish "The Centre for the Advanced Study of Collective Behaviour" from 2019. This ambitious seven-year program (renewable to 14) fosters even closer collaboration between U KN and MPI-AB, and includes two professorships and 10 junior research groups—50% of which are female.

# Future research agenda

We plan to utilize this infrastructure to conduct studies that address fundamental questions regarding sensing and spatiotemporal representation across three levels of biological organization, from neural dynamics, to both individual and collective decision-making. We will integrate mathematical analysis and our new experimental methodologies to seek connections across scales.

Very recently, we have predicted that the brain should, spontaneously, break multi-choice spatial decisions into a series of binary decisions (resulting from dynamical 'bifurcations') in space-time. We also provide a new hypothesis for effective discrimination among different options. These predictions are being tested in VR experiments on fruit flies, locusts, and zebrafish (our first paper on this topic is in revision at *PNAS*). We intend to continue these studies, and to investigate how the brain generates stochastic and systematic search, as well as the strategies animals use to infer, and integrate, salient social and asocial information when making decisions.

To do so, we will collaborate with neuroscientists, including Armin Bahl, Konstanz (zebrafish), and Peter Dayan, MPI-Cybernetics (rodents, computational neurobiology), to seek a deeper mechanistic understanding of spatial decision-making.

Our recent analysis has also identified a massive blind spot in the study of collective animal behavior: specifically, that 'classic' flocking/schooling models cannot make spatial decisions for more than two options. We are evaluating mechanisms to resolve this theoretically and to test these experimentally.

We will also study how non-linear social interactions scale to collective response (to predators, gradients etc.) in very large groups (both theoretically, and experimentally in our new facility), such as how the propagation of coupled velocity and density modes depends on longitudinal (i.e., "compressive") and "transverse" (i.e., "shear") factors. Following this, we will seek evolutionary drivers that connect individual to higher-order forms of computation.

We will also integrate our theory with field research utilizing advanced drone- and submersible-based 3D imaging that we have developed over the last four years. We will study a number of field systems, including multi-species hunting groups of octopus and fish on coral reefs, wild-dog hunting packs in South Africa, zebra herds in Kenya, and massive grazing herds of gelada monkeys in the mountains of Ethiopia.

The aim of our conceptual and theoretical program will, therefore, be to reveal new insights about collective computation across biological scales, from neural dynamics, to both individual and collective decision-making.

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# Highlights

### January 2019

Successful €30.5M application to establish the German Research Foundation Cluster of Excellence "The Centre for the Advanced Study of Collective Behaviour" at the University of Konstanz.

### October 2019

Couzin was awarded the Lagrange Prize, "the first and most important international award that recognizes excellence in complex systems science across all disciplines."

### 2018–2021

Couzin was consecutively listed as a Web of Science (Clarivate, formerly Thompson Reuters) Global Highly Cited Researcher.

## Most important publications

| | | |
|---|---|---|
| 159 | **Lutz MJ**, Reid CR, Lustri CJ, Kao AB, Garnier S, **Couzin ID**. 2021. Individual error correction drives responsive self-assembly in army ant scaffolds. *Proceedings of the National Academy of Sciences* 118: e201374. | *Seemingly-collective "scaffolding" structures, never studied before, proved to result from a novel proportional control mechanism mediated via individual-level error sensing and correction, with no communication among ants. [4 citations]* |
| 277 | **Walter T, Couzin ID.** 2020. TRex, a fast multi-animal tracking system with markerless identification, and 2D estimation of posture and visual fields. *eLife* 10: e64000. | *Enabling open access to technologies for next-generation, replicable behavioral studies, TRex (~25x faster and utilizing ~6x less memory than commercial alternatives) allows multi-animal tracking and markerless individual-recognition for almost any species. [3 citations]* |
| 339 | **Li L, Nagy M, Graving JM,** Bak-Coleman J, Xie G, **Couzin ID.** 2020. Vortex phase matching as a strategy of schooling in robots and in fish. *Nature Communications* 11: 1-9. | *We developed bio-mimetic robotics, computational fluid dynamics, analytic hydrodynamic modeling, and deep-learning-based tracking of real fish, to reveal the strategy that fish employ to exploit hydrodynamic interactions when schooling. [4 citations]* |
| 188 | Sosna M, Twomey CR, Bak-Coleman J, Poel W, Daniels BC, Romanczuk, P, **Couzin ID**. 2019. Individual and collective encoding of risk in animal groups. *Proceedings of the National Academy of Sciences* 116: 20556-20561. | *The brain is often considered responsible for intelligence. We demonstrated a complementary form of computation, encoded not in individual-level response to cues, but in the structure of the interaction network. [16 citations]* |
| 273 | Flack A*, **Nagy M*,** Fiedler W, **Couzin ID,** Wikelski M. 2018. From local collective behaviour to global migratory patterns in white storks. *Science* 360: 911-914. *co-first authors | *By integrating quantitative analyses and theoretical predictions, developed in our Department (Nagy), with the tracking capabilities of the Wikelski group (Flack), we revealed important leader-follower roles in natural migrating flocks. [54 citations]* |

*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

*All publication and citation figures and metrics are based on Web of Sciences on May 31, 2021.*

*Dept./Group members in bold.*

*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*



## Max Planck Director

# Iain D. Couzin

+ PhD: 1999, University of Bath, with Nigel Franks
+ Past positions: Postdoc, University of Leeds, University of Oxford and Princeton University (2002-2007), Assistant Professor (2007), and Full Professor (2013) at Princeton University, Full professor at University of Konstanz (since 2014)
+ Joined MPI: 2014 as Director
+ Selected fellowships, grants & awards: Searle Scholar Award (2008), National Geographic Society Emerging Explorer Award (2012), Scientific Medal of the Zoological Society of London (2013), Lagrange Prize for outstanding contributions relevant to the progress of complexity science (2019), Global Highly Cited Researchers List by the Web of Science Group (2018-2021)
+ Lifetime publication record: 128 publications, 12,334 citations, h-index: 52
+ Mean hours of teaching per week during semesters at U KN: 3

## Department of Collective Behavior

**22**
Number of group members

**86**
Number of peer-reviewed papers

**73%**
Percentage international group members

**41%**
Percentage female group members

**2**
Number of finished Doctoral Students

**5 BSc & 3 MSc**
Number of finished students

**2,134,000 €**
Third-party funding granted (Top 3 sources: US Office of Naval Research, European Union, CASCB)

# SOCIAL EVOLUTIONARY ECOLOGY LAB

**PI: DAMIEN FARINE**

Social behaviors are fundamental in shaping the interface between individuals and their environment. Yet this interface has remained challenging to understand because it requires studying how individuals in groups and populations interact over long periods of time. The Social Evolutionary Ecology Lab has been addressing this challenge by combining computational and theoretical models, experimental manipulations of social groups, and long-term tracking of individuals in both captive and wild animal populations. Combining these approaches with state-of-the-art analytical tools has allowed the lab to have a major scientific impact, as evidenced by the high standard of publications, grants awarded, and the successful progression of early-career researchers.

## Research achievements

The Social Evolutionary Ecology Lab aims to understand how individuals contribute to their group, whether contributions are shaped by ecological conditions, and how the environment that individuals experience shapes their future decisions (Figure II.2). We have addressed these questions using empirical, theoretical, and conceptual approaches. The latter include contributions formalizing how social structures can be described and compared (1, 2); theoretical studies exploring their evolution (3-7); and conceptual works on the implication of social structure for eco-evolutionary processes (8-11). We have also made substantial contributions to the development of analytical methods for studying social behavior, including considerations in terms of data collection (12), inferring social structure (13-19), and interpretation of results (20). However, most of our focus has been on empirical studies.

Using long-term observational and GPS tracking of wild vulturine guineafowl, we have shown how groups make decisions (21), how group size (22) and seasonal conditions (23) affect movements, and how subadults disperse between groups (24). The richness of our data was central to allowing us to reveal the multilevel social structure of our study population (25), the first outside of primates. We have since argued that such structure might be common in birds (26), and recent collaborative work with a former lab student supports this (27).

To gain a finer-scale perspective of how social interactions shape social systems, we developed an automated system (28), and more recently deep learning-based methods (29), for individual recognition that can continuously track captive colonies of zebra finches. Using four colonies across two generations, we have zoomed into how pairs form (30) and tested whether social relationships are inherited (31). We are currently using this system to test key hypotheses relating to social structure extra-pair paternity (11), and a jointly advised Doctoral Student working on blue tits has already found evidence in support for these hypotheses (32, 33).


*Figure II.2 –*
*Research focus of the Social Evolutionary Ecology Lab*

We have more recently been conducting data collection focused on within-individual physiological outcomes of the social environment. Using implanted heart rate loggers (guineafowl) and stress manipulations (zebra finches), we are testing the feedbacks arising from the social environment on individual states. The zebra finch project forms part of a large comparative study on stress transmission by the CASCB at the University of Konstanz.

Nowhere is the integration of state-of-the-art methods with empirical systems better demonstrated than our work on the seemingly cooperative foraging between artisanal fishers and wild dolphins at Laguna, Brazil. In our collaboration with the Universidade Federal de Santa Catarina, we have developed a multi-platform data collection system combining overhead and underwater imaging with hydrophones to study dolphins, and GPS and heart-rate tracking of fishers. Our study (34) conclusively demonstrates the short-term foraging benefits that both dolphins and fishers gain from cooperating, how this interaction generates long-term benefits for dolphins, and the importance of foraging synchrony in the long-term stability of this endangered subspecies of dolphins.

Our research has drawn substantial external funding, including from the DFG, the ERC, the CASCB, the DAAD, the National Geographic Society, the Daimler und Benz Stiftung, the Zukunfstkolleg at the University of Konstanz, the Alexander von Humboldt Stiftung, CAPES-Brazil, and the Association for the Study of Animal Behaviour.

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## Most important publications


**Cantor M, Maldonado-Chaparro AA,** Beck KB, **Brandl HB, Carter GG, He P,** Hillemann F, Klarevas-Irby JA, **Ogino M, Papageorgiou D, Prox L, Farine DR.** 2021. The importance of individual-to-society feedbacks in animal ecology and evolution. *Journal of Animal Ecology* 90: 27-44.

*A large review of the knowledge generated over the past decade by applying network tools to social animals highlights the remaining widespread gaps in the study of feedbacks in social systems. [4 citations]*


**Ferreira AC**, Silva LR, Renna F, **Brandl HB**, Renoult JP, **Farine DR**, Covas R, Doutrelant C. 2020. Deep learning-based methods for individual recognition in small birds. *Methods in Ecology and Evolution* 11: 1072-1085.

*First evidence that marker-less individual recognition can work with small birds, including two model systems in birds: the great tits and zebra finches. Foundation for revolutionizing tracking in avian studies. [12 citations]*


**Papageorgiou D**, Christensen C, Gall GEC, **Klarevas-Irby J**, Nyaguthii B, Couzin ID, **Farine DR.** 2019. The multilevel society of a small-brained bird. *Current Biology* 29: R1120-R1121.

*The first study to translate the multilevel society concept from evolutionary anthropology to a population of wild birds, and demonstrates the value of population-scale GPS tracking studies. [19 citations]*


**He P, Maldonado-Chaparro AA, Farine DR.** 2019. The role of habitat configuration in shaping social structure: a gap in studies of animal social complexity. *Behavioural Ecology & Sociobiology* 73: 9.

*Argues that the physical configuration (i.e., shape) of the environment is a rarely considered factor shaping social network structure in animal populations. [39 citations]*


**Maldonado-Chaparro AA, Alarcón-Nieto G, Klarevas-Irby JA, Farine DR.** 2018. Experimental disturbances reveal group-level costs of social instability. *Proceedings of the Royal Society* B 285: 20181577.

*Demonstrates how key events in groups' histories can have lasting impacts on fundamental behaviors. Pioneered the use of a powerful, yet inexpensive method for long-term studies in replicated social groups. [27 citations]*

*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

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*Dept./Group members in bold.*

*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*





## Principal Investigator

# Damien Farine

+ PhD: 2013, University of Oxford, with Ben C. Sheldon
+ Past positions: Postdoc, University of Oxford (2013-2015), Smithsonian Tropical Research Institute research fellow, University of California Davis (2014-2015)
+ Joined MPI: 2015-2020 as PI; non-tenured since 2020, Professor at Zurich University and Affiliated Scientist at MPI-AB
+ Selected fellowships, grants & awards: DFG (2018), ASAB Christopher Barnard Award (2018), Global Highly Cited Researchers List by the Web of Science Group (2019+2020), ERC starting grant (2019)
+ Lifetime publication record: 111 publications, 3,800 citations, h-index: 33
+ Mean hours of teaching per week during semesters at U KN: 5

## Social Evolutionary Ecology Lab

**8**
Number of group members

**76**
Number of peer-reviewed papers

**100%**
Percentage international group members

**50%**
Percentage female group members

**1**
Number of finished Doctoral Students

**6 BSc & 4 MSc**
Number of finished students

**2,109,000 €**
Third-party funding granted (Top 3 sources: European Union, German Research Foundation (DFG), CASCB)

# RESEARCH GROUP INTEGRATIVE BEHAVIORAL ECOLOGY

**GROUP LEADER: ALEX JORDAN**

The Integrative Behavioural Ecology Group seeks to understand the evolutionary pathways from simple to complex behavior in animals. We use modern approaches to behavioral tracking and analysis, in combination with field studies of adaptive value and evolution, allowing us to quantify and compare complex social behaviors across species boundaries, even in the most challenging field environments. Our aim is to develop a truly integrative approach to the study of animal social behavior, combining lab studies of proximate neurobiological and genetic mechanisms of social behavior, theoretical analyses based on the physics of interactions, and broad evolutionary and ecological studies of social behavior across taxonomic boundaries.

## Research achievements

We strive to bridge the gap between the quantitative power of lab experiments and the realism of research in natural environments, studying both the broad scale evolutionary patterns of behavior, as well as the immediate adaptive value of animal social behavior in natural contexts. Since starting the Group, we have capitalized on the opportunity to build up a powerful study system in comparative behavioral research—the Lake Tanganyikan cichlid adaptive radiation—which has long been a model for evolutionary comparison of morphological traits such as color and anatomy. We are extending this work into the behavioral realm, creating a framework for analyses of behavior in natural settings, allowing rigorous, quantitative comparisons of behavioral repertoires among species. We us machine-learning approaches to analyse behavior, building on advances in lab-based model organism studies, but we translate these approaches to make them accessible and applicable in field settings throughout Africa and Central America, using low-cost, open-source approaches. We have also expanded our taxonomic range to capitalise on similarly powerful comparative systems, in both Mediterranean wrasse and social spiders. The explicit goal of the group is to create a bridge between the fine-scale behavioral and mechanistic analyses that can be conducted in the lab, and the broadscale adaptive and evolutionary questions that can only be answered in the field. At both levels, we leverage cutting-edge advances in computational techniques to answer fundamental questions about the evolution and mechanisms of social behavior. Ultimately we want to understand how and why animals develop complex behavioral traits and evolve to be more social.

### ADAPTIVE RADIATION OF BEHAVIOR - LAKE TANGANYIKAN CICHLIDS

A primary focus in the Group has been the development of the shell-dwelling cichlid fishes of Lake Tanganyika, and we have become a leader in the use of this species group in comparative evolutionary studies (1). These unassuming fish provide an unparalleled opportunity to understand how behavior has evolved, showing extreme variation in social structures and behaviors while having otherwise highly overlapping life histories, ecology, distribution, and an extremely well-resolved phylogeny (Figure II.3). We use comparative approaches to study

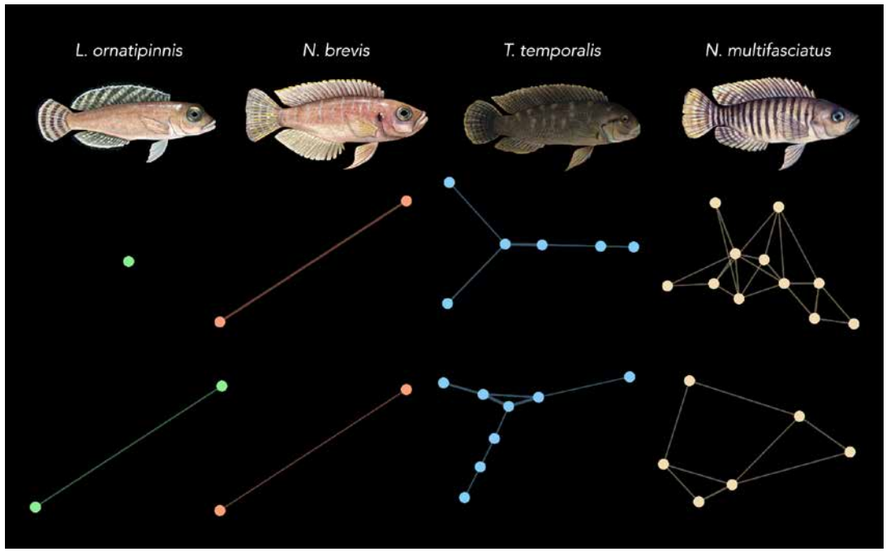


*Figure II.3 –*
*Example social (behavioral interaction) networks for four species of Lamprologine cichlids that show increasing degrees of social complexity. Adapted from Lein & Jordan (in review).*

10 of these species, performing predominantly in situ studies in the southern reaches of Lake Tanganyika, where we have developed expertise in capturing underwater video in natural habitats while scuba-diving. With these recordings, we use machine learning-based tracking to gather highly detailed measurements of the behavior of freely moving, interacting, and behaving animals (2, 3). Our approach combines the precise detail of behavioral observations in lab conditions (4), with the realism of observing untagged, unmanipulated animals in their natural environments (3). We are even able to directly modify the physical environment of our study species using CT-scanning, digital manipulation, and 3D-printing of shells to explore preferences for natural structures (5). Finally, in the past years, we have generated brain atlases for each of the species (6), and we are now able to explore patterns of neuronal activity and gene expression during social behaviors (7), creating a unique system in which we can explore both the mechanisms of behavior as well as their adaptive significance.

### CONTINUITY IN QUESTIONS AND SYSTEMS

At the same time, we have continued with existing questions and systems. Our work studying cognition and consciousness (e.g., in cleaner wrasse; 8) has expanded, employing new approaches using tracking to decompose behavioral responses in the controversial mirror test, as well as field explorations of mirror responses across Mediterranean wrasse species. In our recent *PNAS* paper, we extended Jordan's postdoctoral work by employing machine learning-based tracking and analysis of behavior to reveal the mechanisms of social influence in hierarchical animal groups (4; Figure II.4). We have also continued work in social spiders, extending our initial studies in captive conditions with fieldwork in Panama and Namibia, incorporating analytical approaches based on theoretical physics in these studies (9).

Based on our initial investment in developing new systems and techniques, the Group is rapidly increasing in size and productivity. In the past 24 months, we have won major collaborative grants (HFSP, NSF, FCT), attracted externally funded postdocs (AvH, Zukunftskolleg), external doctoral stipends (CSC, DAAD, TBA-21), had fifteen papers accepted in journals including *PNAS* and *PRSB*, with five additional papers currently in review in journals including *PNAS* and *PLoS Biology*. We have graduated 10 BSc and 7 MSc students, and hosted four Postdocs.

# Future research agenda

Our Group aims to answer the deceptively simple question of how the behavior of one animal in a group influences the behavior of another. In asking this question, our research crosses disciplinary borders and touches on a multitude of biological fields. From the proximate neurobiological mechanisms that produce behavior, through the development of cognitive skills, to the ecological structure of entire communities, the rules of social interaction can scale up to shape entire evolutionary processes. The next generation of breakthroughs in behavioral ecology will require an integrative approach that combines areas of expertise to tackle the fundamental questions about the mechanisms of behavior, and the sources of selection acting on them to produce the social structures we see in natural populations. In the next five years and beyond, it is our aim to reveal the basic rules of interaction among animals in complex social contexts to answer fundamental evolutionary and ecological questions that have long seemed intractable. Does behavioral evolution require the development of novel kinematic forms? Are existing patterns of behavior co-opted to have novel functional effects in more socially complex species? Does increasing social complexity lead to increased cognitive capacity, and if so, is this reflected in the neuroanatomy or patterns of neural activity in social species? What is the role of the extended phenotypes and environmental structures that animals produce or inhabit?

In its time at the MPI-AB, our Group has been able to develop world-leading data acquisition and analysis techniques that dovetail with numerous fields, resulting in collaborations across disciplines from computer science, physics, neurobiology, and art. In the coming years, we will build on our work to explore the adaptive value of variation in social behavior among different species, we will examine the kinematic structure and evolutionary development of behavioral elements across the cichlid radiation, and we will determine how the brain encodes divergent social responses across species. In all these inquiries, we keep evolutionary theory and the natural behavior and ecology of our systems at the forefront of our study design, aiming for an in-depth, integrative understanding of animal behavior situated in the places these species live and have evolved.

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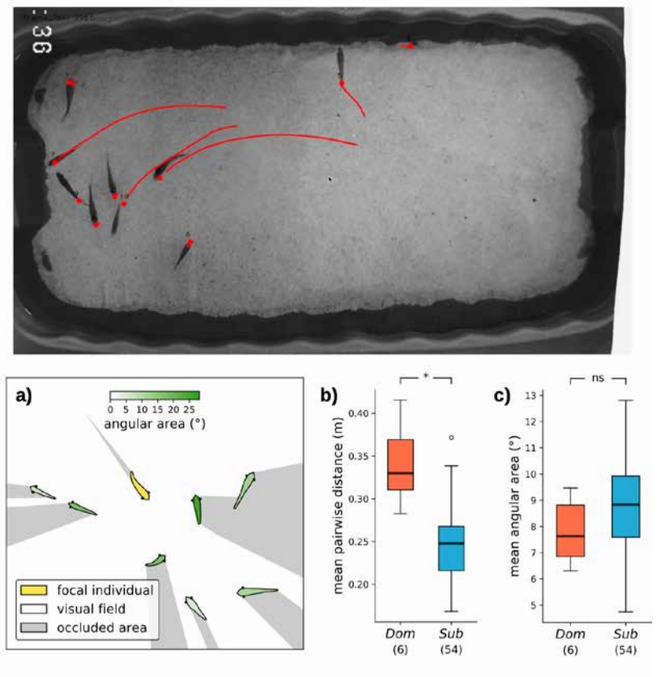


*Figure II.4 -*
*Top: tracking of social interactions in untagged, free-swimming cichlids using machine-learning approaches. Bottom: analyses of behavioral, spatial, and visual interactions in social groups. Adapted from Rodriguez-Santiago, Nuehrenberg et al 2020.*

# Highlights

## February 2019

This controversial paper demonstrates that a fish passes the famous mirror test, and asks whether current approaches in assessing animal intelligence are reasonable across taxonomic boundaries. Featured in *The Guardian, ARTE*, and *National Geographic*.

## March 2019

Jordan was selected to take part in *The Current*, a program from the Thyssen-Borneminsza Art Contemporary Foundation linking artists with scientists, leading to an ongoing Doctoral Student in the lab.

## May 2019

Jordan's research was showcased in two exhibits at the Venice Biennale 2019, with Studio Tomás Saraceno, and ArtScience Exhibits Berlin, with both oral presentations (Giardini Pavilion 7) and artworks on display.

## Most important publications

| | | |
|---|---|---|
| 7 | **Lein E, Jordan A.** 2021. Studying the evolution of social behavior in Darwin's Dreampond – a case for the Lamprologine shell cichlids. *Hydrobiologia* 848: 3699–3726. | *This paper sets the scene for our ongoing behavioral work in the Lake Tanganyikan cichlid adaptive radiation, and cements our group's place as a leader in this system. [0 citations]* |
| 194 | Rodriguez-Santiago M*, **Nührenberg P***, Derry J, Deussen O, **Francisco F**, Garrison LK, **Garza SF**, Hofmann A, **Jordan A**. 2020. Behavioral traits that define social dominance are the same that reduce social influence in a consensus task. *Proceedings of the National Academy of Sciences* 31: 18566-18573. *co-first authors | *This paper brings together the techniques and conceptual approaches from our Group into one manuscript examining a fundamental question in social behavior—who influences whom—and answering this using cutting-edge behavioral analyses. [1 citation]* |
| 72 | **Bose A*, Windorfer J***, **Böhm A**, Ronco F, Indermaur A, Salzburger W, **Jordan A**. 2020. Structural manipulations of a shelter resource reveal underlying preference functions in a shell-dwelling cichlid fish. *Proceedings of the Royal Society* B 287: 1927. *co-first authors | *Here we explore a core question about evolutionary processes in cichlid fishes, producing 3D-printed shelters to explore preferences for extreme traits, and the subsequent impact on co-evolutionary processes. [1 citation]* |
| 21 | **Francisco F, Nührenberg P, Jordan A.** 2020. High-resolution, non-invasive animal tracking and reconstruction of the local environment in aquatic systems. *Movement Ecology* 8: 27. | *This methods paper, written by two then MSc students of the Group, demonstrates an accessible, economical, and flexible approach to tracking wild, untagged animals in underwater environments while also creating 3D topographical maps of the environment. [5 citations]* |
| 1294 | Kohda M, Hotta T, Takeyama T, Yoshimura N, **Jordan A.** 2019. If a fish can pass the mark test, what are the implications for consciousness and self-awareness testing in animals? *PLoS Biology* 17: e3000021. | *This controversial paper demonstrates that a fish passes the famous mirror test, and asks whether current approaches in assessing animal intelligence are reasonable across taxonomic boundaries. [42 citations]* |

*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

*All publication and citation figures and metrics are based on Web of Sciences on May 31, 2021.*

*Dept./Group members in bold.*

*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*



## Group Leader

# Alex Jordan

+ PhD: 2011, University of New South Wales, with Robert Brooks and Ashley Ward
+ Past positions: Postdoc, Osaka City University (2012), Postdoc, University of Texas, Austin (2013-2015)
+ Joined MPI: 2016 as Group Leader; tenured (2020)
+ Selected fellowships, grants & awards: Heineman Research Grant (2016), TBA21 Research Grant (2018), HFSP Young Investigators' Grant (2019), CASCB Medium Grant (2020)
+ Lifetime publication record: 41 publications, 616 citations, h-index: 16
+ Mean hours of teaching per week during semesters at U KN: 6

## Integrative Behavioural Ecology Group

**10**
Number of group members

**28**
Number of peer-reviewed papers

**70%**
Percentage international group members

**30%**
Percentage female group members

**0**
Number of finished Doctoral Students

**10 BSc & 7 MSc**
Number of finished students

**852,000 €**
Third-party funding granted (Top 3 sources: HFSP, CASCB, International Foundation)

# DEPARTMENT ECOLOGY OF ANIMAL SOCIETIES

# DEPARTMENT ECOLOGY OF ANIMAL SOCIETIES

**DIRECTOR: MEG CROFOOT**

For many animals, ecological and evolutionary success depends not only on the characteristics or decisions of lone individuals, but also on what happens when groups of individuals come together and interact. These group-level behaviors and traits are important because they can transform the social landscape, giving rise to novel selective pressures that drive the evolution of social complexity. Our research seeks to answer the fundamental question: how do animal societies emerge and function? Because within- and between-species comparison is critical to understanding the causes and consequences of social variation, we aim to build a common framework for measuring, analyzing, and interpreting the interactions—from dyad to group to population—that comprise the 'sociome.'

## Research achievements

### A TOOL-KIT FOR COMPARATIVE RESEARCH

A major focus of the Department since its founding in mid-2019 has been developing a methodological toolkit for conducting comparative research on the causes and consequences of variation in the structure of social relationships between groups, among populations, and across species. To overcome inherent limitations in the scale of observational methods, we have made significant strides towards developing automated classifiers to infer individual behavior, dyadic interactions, and group-level state from remotely sensed data (e.g., accelerometry, GPS, audio; 1).To disambiguate hypothesized drivers of individual influence in group decision-making, we have designed, built, and field-tested arrays of wirelessly networked, RFID-controlled feeders that will allow us to conduct controlled experiments under socially and ecologically relevant field conditions. Thermal videography (Figure II.5) and accelerometry make the nighttime behavior and sleep patterns of baboons observable (2), and are providing us with a context for studying group decision-making where the impact of collective decisions on individual group members can be readily quantified (i.e., sleep quality). In conjunction with the Advanced Research Technology Unit and the Department of Migration, we have expanded the functionality and flexibility of our animal tracking technology. This includes incorporating acoustic recorders to study the role of communication in group decision-making; proximity loggers for mapping differences between, and changes in, groups' social networks; and remote data access via Sigfox network, allowing monitoring of key demographic events in real-time. We have also published papers aimed at improving capture methodology with our collaborators from the Kenya Wildlife Service, Drs. Maureen Kamau and Mathew Mutinda (3, 4).

### TOOL-USE TRADITIONS IN CAPUCHINS

Cultural traditions are an important source of behavioral variation in some animal species, but we still do not understand how they arise, why they persist, and when they (sometimes) spread. Our recent discovery of tool-using capuchins living on islands in the Coiban Archipelago (5, 6) creates a unique opportunity to address these questions: multiple isolated populations with known divergence times, having largely similar ecologies but different population sizes, where some groups habitually incorporate stone-tool use into their foraging repertoire, whereas in other (adjacent) groups, this tradition appears to be entirely absent. The first camera trapping survey (Figure II.6) of the archipelago by Claudio Monteza-Moreno (IMPRS Doctoral Student) documented substantially higher rates of terrestriality compared to mainland populations, in conjunction with extremely high population densities and a complete absence of terrestrial, mammalian predators (7). To investigate how such differences influence the emergence of tool-use traditions, Brendan Barrett (Postdoc), the leader of this project, has partnered with Lydia Luncz (MPI for Evolutionary Anthropology) to establish a research consortium aiming to standardize data collection and conduct large-scale comparative analyses across studies of stone-tool using and non-tool using primate populations. We have also completed two natural history manuscripts arising from observations made during our research on the Coiban Archipelago, both first-authored by Panamanian undergraduate students working with us on this project (Pedro Castillo-Caballero (8); Evelyn del Rosario-Vargas (9)).

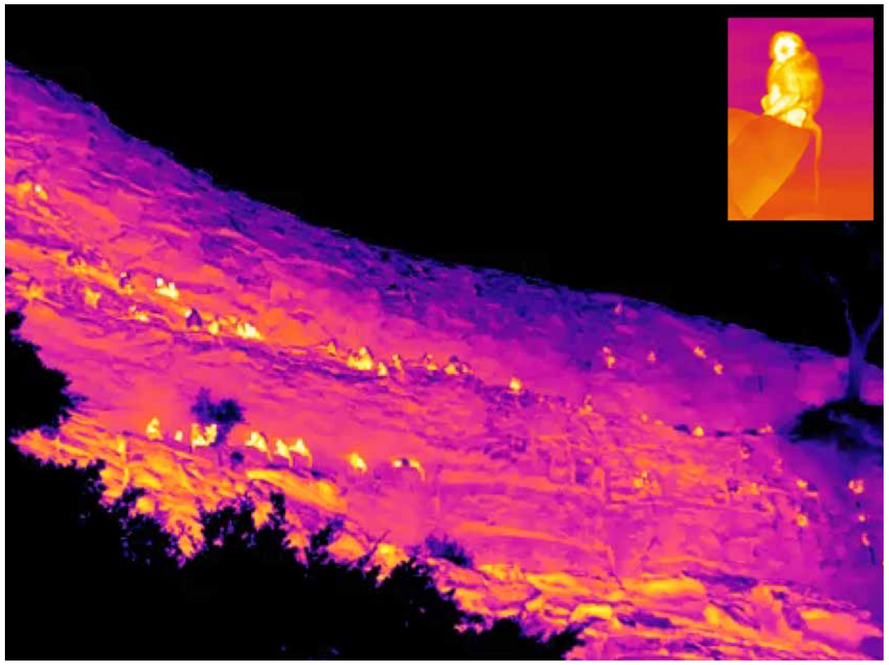

*Figure II.5 – Thermal cameras allow us to track the decisions baboons make about where in the sleep site to position themselves, as well as quantify how these choices impact the quality of their sleep.*

## Future research agenda

The main focus of the Department over the next five years will be to build the study systems, methodological capacity, and collaborative partnerships that will serve as the foundation for our long-term research objectives. At the Mpala Research Center in Kenya, we are developing a study system designed to address questions about the causes and consequences of between-group variation in social structure: eight to ten habituated baboon troops, embedded in a landscape of 30–40 remotely-tracked neighboring groups. The habituated groups will serve as a platform for a variety of experimental and observational studies that require more detailed information about social relationships among groupmates, including research led by Roi Harel (Postdoc) that uses our RFID-controlled feeders to test hypotheses about group decision-making, and work led by Carter Loftus (Doctoral Student) on the collective dynamics of sleeping in groups. Neighboring groups, tracked with long-lasting proximity loggers, will contribute to a comparison of population-level interaction networks conducted in collaboration

with Andrea Migliano (University of Zurich), provide adequate sample size for group-level comparisons, and allow Chase Nuñez (Postdoc) to answer questions about how dispersing male baboons navigate their social and non-social environment. In collaboration with Michelle Brown (University of California), we will learn how habitat structure (tropical forest vs. savannah woodland) impacts group decision-making via a comparison of olive baboons at Mpala (woodland savanna) and Ngogo (tropical forest). Ultimately, we aim to build a research consortium to expand this comparative research across baboon species.

How the distribution and abundance of food resources shapes the structure of animal societies has been a primary concern of primate research for nearly four decades. A fundamental mismatch between the scale at which decision-making occurs and the scale at which we can map the resource base has severely impeded our ability to test existing theory. To bridge this gap, we are taking advantage of recent reductions in the size and weight of environmental sensors and extending methods from precision-agriculture to map nutritional landscapes at consumer-relevant scales. With support from scientists in our Advanced Research Technologies Unit, Kate Tiedeman and Shauhin Alavi (Postdocs) are developing deep learning models to identify ripe (and ripening) fruit in a suite of remotely sensed data, including hyperspectral imagery, thermal imagery, and LiDAR. We have designed a module to mount these sensors on any small, Cessna-sized plane, creating a flexible platform that can be transported to field sites around the world.

To uncover general rules that govern the functioning of complex animal societies, we are building a cross-species dataset of communication and collective movement, with studies of the greater spear-nosed bats (Camilla Calderon), wild dogs (Alison Govaerts), hyaenas (Eli Strauss), coati (Emily Grout), meerkat (Baptiste Averly), dhole (Linnea Havmoeller), baboons (Roi Harel), sifaka (Tracy Montgomery), and fossa (Zea Walton) currently underway. We are also laying the groundwork for two major cross-site comparisons. One focuses on how the structure of within- and between-group contacts determines the flow of information about predator-presence in Verreaux's sifaka populations (initial study at Kirindy Mitea in collaboration with Rebecca Lewis). The other seeks to understand the causes and social and ecological consequences of ranging traditions in white-faced capuchins (initial collaboration with Susan Perry at Lomas Barbudal, in progress). Last, we are seeking to address the loss of irreplaceable data that occurs when behavioral ecologists leave the field, retire or die. Starting with movement data, but with plans to expand to behavioral and environmental datasets, we seek to digitize, archive, and preserve these historic resources for use by future generations of scientists and to address a range of questions that require large comparative datasets or involve a significant time-depth component. This is part of our broader goal to establish the MPI-AB as a global hub for comparative research on animal societies, building collaborative networks of researchers committed to standardizing data collection methods and sharing data to realize the full potential of long-term field studies to reveal how animal societies emerge and function.

## REFRENCES

**1** Muscioni, et al. 2019. *arXiv*:1907.00932; **2** Loftus, et al. in review; **3** Mutinda et al. 2019. *International Journal of Primatology* 40: 187-196; **4** Kamau et al. revised & resubmitted. *International Journal of Primatology*; **5** Monteza-Moreno, et al. 2020. *International Journal of Primatology* 41: 429-433; **6** Barrett, et al. 2018. *Journal of the Royal Society Open Science* 5: 181002; **7** Monteza-Moreno, et al. 2020. *Journal of Human Evolution* 143: 102768; **8** Castillo-Caballero, et al. 2020. *Tecnociencia* 22: 123-149; **9** del Rosario-Vargas, et al. in review.

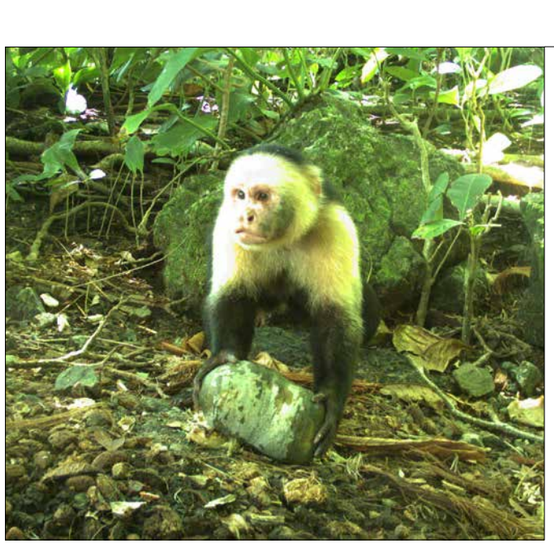

*Figure II.6 -*
*Checking camera traps at the capuchin tool-use sites on Jicaron Island in Coiba National Park, with Zarluis Mijango Ramos (botanist & Doctoral Student, University of Illinois, Urbana Champaign), Claudio Monteza Moreno (mammologist & Doctoral Student, IMPRS), Meg Crofoot (behavioral ecologist, MPI-AB) and Tamara Dogandžić (archaeologist, University of Pennsylvania).*

# Highlights

## June 2019

Ecology of Animal Societies Department established at the MPI-AB / U KN, supported by an Alexander von Humboldt Professorship

## May 2020

Discovery of the only known tool-using population of gracile capuchins on the Coiba Archipelago in Panama (5, 6)

## 2019-2021

Successful recruitment of 24 scientists and 5 students from around the world, during a global pandemic.

## Most important publications

| | | |
|---|---|---|
| 19 | Noonan MJ, Martinez-Garcia R, **Davis GH, Crofoot MC,** Kays R, Hirsch BT, Caillaud D, Payne E, Sih A, Sinn DL, Spiegel O, Fagan WF, Fleming CH, Calabrese JM. 2021. Estimating encounter location distributions from animal tracking data. *Methods in Ecology and Evolution* 12: 1158-1173. | *We introduce a new analytical method for describing spatially explicit long-term encounter probabilities for moving animals inhabiting stable home ranges. This method extends movement ecologists' analytical toolkit, allowing researchers to address questions about the relationship between animal movement and the rates of encounters with neighborhood, but also about the spatial location of these encounter events in the environment. [1 citations]* |
| 52 | **Monteza-Moreno CM**, Dogandžić T, McLean KA, Castillo-Caballero PL, Mijango-Ramos Z, Del Rosario-Vargas E, **Crofoot MC, Barrett BJ.** 2020. White-faced capuchin, *Cebus capucinus* imitator, hammerstone and anvil tool use in riparian habitats on Coiba Island, Panama. *International Journal of Primatology* 41: 429-433 | *Documents a second, independent population of tool-using capuchins, living on the island of Coiba in the Coiban Archipelago. Unlike the tool-using population we discovered on Jicaron, both male and female capuchins on Coiba use tools, providing an opportunity to investigate when and why strong sex biases in tool-use emerge. [0 citations]* |
| 56 | **Monteza-Moreno CM, Crofoot MC,** Grote MN, Jansen PA. 2020. Increased terrestriality in a Neotropical primate living on islands with reduced predation risk. *Journal of Human Evolution* 143: 102768. | *Results of our first camera trap deployments on Jicaron and Coiba confirm the absence of mammalian predators on these islands and document unusually high rates of terrestrial behavior in the capuchin population, both of which may be linked to development of their unusual tool-use tradition. [0 citations]* |
| 41 | **Tórrez-Herrera LL, Davis GH, Crofoot MC**. 2020. Do monkeys avoid areas of home range overlap because they are dangerous? A test of the risk hypothesis in white-faced capuchin monkeys (*Cebus capucinus*). *International Journal of Primatology* 41: 246-264. | *Demonstrates that capuchins alter their activity budgets and foraging behavior as a function of location within their home range, but not in ways that are consistent with optimal foraging theory. 'Overexploitation' of resources located in areas of home range overlap suggests that capuchins may pursue a form of indirect territorial defense via resource competition. [6 citations]* |
| 39 | Kays R, Sheppard J, Mclean K, Welch C, Paunescu C, Wang V, Kravit G, **Crofoot MC.** 2019. Hot monkey, cold reality: surveying rainforest canopy mammals using drone-mounted thermal infrared sensors. *International Journal of Remote Sensing* 40: 407-419. | *Drone-based surveys using a thermal camera matched with traditional, ground-based survey methods demonstrate the limitations of thermal imagery for detecting animals in tropical forest environments. [24 citations]* |

*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

*All publication and citation figures and metrics are based on Web of Sciences on May 31, 2021.*

*Dept./Group members in bold.*

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*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*





## Max Planck Director

# Meg Crofoot

+ PhD: 2008, Harvard University, with Richard Wrangham
+ Past positions: Lecturer, Princeton University (2008–2012), Postdoc Smithsonian Tropical Research Institute + MPI for Ornithology (2008–2013), Assistant Professor (2013-2017) + Associate Professor (2017-2019), University of California, Davis, Humboldt Professor, University of Konstanz (since 2019)
+ Joined MPI: 2019 as Director
+ Selected fellowships, grants & awards: NSF-DIOS (2012), NSF-BCS (2014), NSF-CISE (2015), NSF-SMA (2016), Packard Fellowship in Science and Engineering (2016), Humboldt Professorship (2018)
+ Lifetime publication record: 46 publications, 1,761 citations, h-index: 20
+ Mean hours of teaching per week during semesters at U KN: 3

## Department Ecology of Animal Societies

**27**
Number of group members

**28**
Number of peer-reviewed papers

**85%**
Percentage international group members

**59%**
Percentage female group members

**0**
Number of finished Doctoral Students

**1 BSc & 0 MSc**
Number of finished students

**5,000,000 €**
Third-party funding granted (Alexander von Humboldt Foundation)

# RESEARCH GROUP BONOBO BEHAVIORAL ECOLOGY

## GROUP LEADER: BARBARA FRUTH

Bonobos show striking peculiarities that challenge biological paradigms: female bonding despite female exogamy; female dominance despite male-biased sexual-dimorphism; sex independent of reproduction; and low aggression within and between groups. In the Bonobo Behavioral Ecology Group, we integrate data from the LuiKotale fieldsite, Democratic Republic of the Congo (DRC), monitoring reproductive patterns, parental investment, health issues, and individual strategies to cope with the challenges provided by social and environmental constraints. Linking individual physiological parameters to behavior, considering food availability and choice within this highly complex ecosystem, we seek to explain behavioral patterns on both the individual and group levels.

## Research achievements

The Bonobo Behavioral Ecology Group began in January 2021 when Barbara Fruth joined the MPI-AB. The project, however, is based on 20 years of continuous data collection from Fruth's research on the socioecology of bonobos. In recent years, this has focused on bonobo behavior, ecology, and applied conservation, with the goal of investigating the long-term data collected in our study site LuiKotale, DRC.

### THE ECOSYSTEM OF THE CUVETTE CENTRALE

LuiKotale is located just outside Salonga National Park (SNP)—an IUCN Natural World Heritage Site in the Cuvette Centrale. Despite their proximity, the sites have never been compared to determine the extent to which the ecosystems are representative. Between 2016–2018, we conducted a large-scale Camera Trap Distance Sampling (CTDS) covering 17,127 km² of SNP. In our study, Mattia Bessone (Doctoral Student) and collaborators obtained distribution and abundance estimates for 43 animal taxa (1). For some species, these were the first estimates ever recorded. The findings demonstrated the applicability of CTDS for sampling species that differ in size and behavior, as well as the enormous potential of this method for future behavioral (2) and ecological surveys.

When assessing population density and abundance, indirect signs such as nests and feces can be used. For great apes, counting sleeping nests (3) is the gold standard; however, knowing how fast these nests disappear is essential for converting nest counts to ape counts. We investigated the decomposition of 1,511 bonobo nests built between 2003–2018 in the context of climatic data, and uncovered effects of climate change and behavioral adaptations on nest decay time (4). We found a decreasing trend in precipitation across the 15 years of study, which resulted in longer nest decay times. These findings demonstrate the impact of climate change on tropical remote areas of the Central Congo Basin and the delicacy of biomonitoring estimates, which, if not taken into account, could lead to overestimating population density, jeopardizing the conservation of great apes in the wild.

*Figure II.7 –*
*From birth to senility: bonobo life history, a focus of the Group's research agenda*

### BONOBO FEEDING ECOLOGY AND HEALTH

Climate change and anthropogenic impact are also known to accelerate human-animal conflicts in general and zoonotic diseases in particular. Focusing on bonobo health and related behavior, we have been investigating self-medication since 2013 (5, 6). Mélodie Kreyer (Doctoral Student) and collaborators improved our understanding of what triggers this specific ingestion behavior, confirming that *Manniophyton fulvum*, a bristle Euphorbiaceae, was ingested independently of its availability, seasons, and the presence/absence of gastro-intestinal parasites. However, we found a cultural component when comparing ingestion behavior between communities (7).

To interpret such observations from the wild, it is necessary to explore influential parameters such as age, sex, and environment on immune responses. We compared data from captive and wild bonobos, assessing immune ontogeny from birth to adulthood, and found that responses were sex-specific but independent of environmental conditions. This suggests cell-mediated immune ontogeny following a genetically determined pattern not affected by environmental differences in pathogen exposure and energy availability. These results provide a stepping stone for future investigations towards a better understanding of the evolution of life-history strategies, mechanisms of sexual selection, and population dynamics with respect to pathogen susceptibility (8).

### BONOBO LIFE HISTORY

As all great apes, bonobos reflect selection for slow life histories characterized by their late age at first reproduction, long inter-birth intervals, and long lifespans. So far, however, they don't contribute significantly to what we know about great ape species. Many important questions in evolutionary anthropology can only be answered through long-term investigations, and our accumulating data allow unpeeling of demography and life-history strategies (Figure II.7).

# Future research agenda

### THE ECOSYSTEM OF THE CUVETTE CENTRALE

Mammal communities are hunted for meat across the Congo Basin. To judge the impact of hunting for our study site, we will assess the status, trend, and interconnectedness of bonobos and other mammals (Figure II.8). We will continue exploiting (i) the data collected in our two-year large-scale inventory of fauna and flora of SNP; integrating (ii) the ungulate (nine species), and (iii) monkey community (eight diurnal species) to investigate competition and synergies between species. Applying novel technologies, such as arboreal camera traps, GPS tags, and drones, we seek to unlock components of the complex ecosystem and its predator-prey relationships, including humans. We will investigate long-term data integrating the human need for livelihoods across representative times and assess parameters in light of local population growth. Local communities are thus empowered to contribute to new concepts of rainforest protection, by reassessing their role in the ecosystem.

### BONOBO FEEDING ECOLOGY AND HEALTH

Quality of diet is said to have driven hominin brain growth, with iodine playing a crucial role in encephalization. Bonobos provide an interesting model for testing these hypotheses as their habitats in the Cuvette Centrale are considered to be iodine-deficient according to human standards. Following a preliminary study, we aim to explore three interrelated topics: (i) availability of iodine in the habitat; (ii) iodine status of individual bonobos; and (iii) variation of individual iodine status in relation to intake of iodine-containing food. By that, we can link iodine status to ongoing work on development, health, and life history such as the reproductive status of adult females. This will provide new aspects to key evolutionary models. In addition to (i-iii), we intend to investigate the increasing risk for zoonotic diseases. To date, little is known about bonobo eco-immunology and their self-medicating behaviors. To fill this gap, scientific objectives include (iv) expanding existing knowledge on food availability and choice; (v) monitoring individual health; and (vi) uncovering requirements of staying healthy, as well as preventing and treating diseases at the individual and population levels.

### BONOBO LIFE HISTORY

Based on our long-term data, we will investigate the (i) interplay of ecology, behavior, morphology, and life history parameters from birth to death; as well as (ii) physiological parameters. The goal is to revisit hypotheses such as the pace-of-life syndrome (POLS), where behavioral and physiological traits are said to mediate the trade-off between current and future reproduction, revealing selection pressures acting on individuals to develop a slower or a faster pace of life.

### REFRENCES

**1** Bessone, et al. 2020. *Journal of Applied Ecology* 57: 963-974; **2** Kalan, et al. 2019. *Current Biology* 29: 1211-1217; **3** Fruth, et al. 2018. *American Journal of Physical Anthropology* 166: 499-509; **4** Bessone, et al. 2021. *PLoS ONE*; **5** Fruth, et al. 2014. *American Journal of Primatology* 76: 146-158; **6** Fruth, in press. *Journal of the Anthropological Society of Oxford*; **7** Kreyer, et al. in press. *American Journal of Primatology*; **8** Behringer, et al. 2021. *Frontiers in Ecology and Evolution* 9: 629094; **9** Hohmann, et al. 2019. *BMC Zoology* 4: 1-6.

*Figure II.8 –*
*Bonobos are predator and prey. Left: bonobo ingesting a duiker's leg*
*Right: bonobo hunted and smoked by humans*

# Highlights

**January 2021**

Start of new Bonobo Behavioral Ecology Group, allowing the Group to capitalize on synergies with MPI-AB expertise for innovative approaches to advance the LuiKotale Bonobo Project (LKBP).

**January 2020**

Fruth's successful conferment to Full Professorship at Liverpool John Moores University (LJMU) at the first go.

**2019-2020**

Income generation from Leakey Foundation, Ouwehands Zoo Foundation, the Centre for Research and Conservation, and MPI-AB allowed research continuity for LKBP.

## Most important publications

| | | |
|---|---|---|
| 10 | Behringer V, Deimel C, Stevens JMG, **Kreyer M**, Lee SM, Hohmann G, **Fruth B,** Heistermann M. 2021. Cell-mediated immune ontogeny is affected by sex but not environmental context in a long-lived primate species. *Frontiers in Ecology and Evolution* 9: 629094. | *Assessing bonobo immune ontogeny from birth to adulthood, we found immune responses independent of environmental conditions. This prompts future investigations towards a better understanding of the evolution of life-history strategies. [0 citations]* |
| 43 | Corredor-Ospina N, **Kreyer M**, Rossi G, Hohmann G, **Fruth B.** 2021. First report of a leopard (*Panthera pardus*)–bonobo (*Pan paniscus*) encounter at the LuiKotale study site, Democratic Republic of the Congo. *Primates* 62: 555–562. | *Despite 30 years of field research, this is the first direct observation of a predator-prey encounter at LKBP. [0 citations]* |
| 47 | Bessone M, Kühl HS, Hohmann G, Herbinger I, N'Goran KP, Asanzi P, DaCosta PB, Dérozier V, Fotsing EDB, Beka BI, Iyomi MD, Iyatshi IB, Kafando P, Kambere MA, Moundzoho DB, Wanzalire MLK, **Fruth B.** 2020. Drawn out of the shadows: Surveying secretive forest species with camera trap distance sampling. *Journal of Applied Ecology* 57: 963-974. | *This is the first outcome of large-scale application of Camera Trap Distance Sampling, demonstrating applicability to multifold species, and setting the scene for cutting edge methodology for future conservation strategies. [11 citations]* |
| 123 | Hohmann G, Ortmann S, Remer T, **Fruth B.** 2019. Fishing for iodine: what aquatic foraging by bonobos tells us about human evolution. *BMC Zoology* 4: 1-6. | *The first contribution elucidating early continental hominin options for coping with iodine requirements using bonobos as an analogous model. We identified two species of aquatic herbs with notable iodine concentrations. [3 citations]* |
| 126 | **Fruth B**, Hohmann G. 2018. Food sharing across borders: First observation of inter-community meat sharing by bonobos at LuiKotale, DRC. *Human Nature* 29: 91-103. | *Bonobos hunt and share their catch within their community. This is the first observation of sharing outside of the community, marking one extreme of the bonobo social interaction spectrum ranging from peaceful to aggressive. [27 citations]* |

*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

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*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*



## Group Leader

# Barbara Fruth

+ PhD: 1995, University of Munich & Max Planck Research Unit for Human Ethology, with Irenäus Eibl-Eibesfeldt and Gerhard Neuweiler
+ Past positions: Postdocs, Miami-University Oxford, OH, USA (1995-1996); MPI Seewiesen (1996-2001); Research Scientist, MPI Seewiesen (2001-2004), Group Leader, MPI-EVA Leipzig (2004-2013); Senior Lecturer, University of Munich (2014-2016); Associate Professor, John Moores University Liverpool (2016-2020); Full Professor, John Moores University Liverpool (2020)
+ Joined MPI: 2021 as Group Leader; tenured
+ Selected fellowships, grants & awards: Co-director, LuiKotale Bonobo Project (since 2001)
+ Lifetime publication record: 65 publications, 2,594 citations, h-index: 22
+ Mean hours of teaching per week during semesters at U KN: 0

## Bonobo Behavioural Ecology Group

**1 (3)***
Number of group members
* +2 at John Moores University Liverpool

**1**
Number of peer-reviewed papers

**67%**
Percentage international group members

**50%**
Percentage female group members

**0**
Number of finished Doctoral Students

**0 BSc & 0 MSc**
Number of finished students

**57,000 + 110,000* €**
Third-party funding granted (private German foundation, * CRC/KMDA paid directly to LKBP)

# RESEARCH GROUP COMMUNICATION & COLLECTIVE MOVEMENT

## GROUP LEADER: ARIANA STRANDBURG-PESHKIN

From staying together while on the move to banding together against common enemies, social living requires coordination. But how do groups achieve such coordination? What communication strategies do they use? And how might the mechanisms of coordination vary based on social and ecological factors? In the Communication & Collective Movement Group, we study how social groups communicate and coordinate with one another across a range of different species and contexts. Our research combines high-resolution tracking of wild animal groups, experiments, and computational methods to tackle this question, in close collaboration with several long-term research studies around the world.

## Research achievements

The Communication and Collective Movement Group (CoCoMo) was founded in June 2018 at the University of Konstanz and joined the MPI-AB in December 2019. Since our inception, we have grown to include 10 members, including three members who have been awarded their own funding (Vlad Demartsev, Humboldt Fellowship; Gabriella Gall, Zukunftskolleg / CASCB Fellowship; Pranav Minasandra, DAAD scholarship). Our team emphasizes the integration of new technologies and computational approaches with fieldwork in collaboration with long-term studies to tackle questions at the interface of communication and collective behavior.

### COMMUNICATION AND COORDINATION ACROSS SCALES

In December 2019, we kicked off the large-scale research project "Communication and Coordination Across Scales", funded by an HFSP Research Grant. This collaborative project integrates high-resolution tracking with long-term field observations to investigate the interplay among communication and collective behavior across three species of social carnivores. The species we study coordinate with one another across a spectrum of spatial scales, from highly cohesive meerkat groups (Kalahari Meerkat Project, with Marta Manser), through moderately cohesive coati groups (Barro Colorado Island, with Ben Hirsch and Meg Crofoot), to fission-fusion hyena clans (MSU-Mara Hyena Project, with Kay Holekamp). Each species also employs a large and well-characterized repertoire of vocalizations known to be associated with group coordination. Together, these three study systems provide a rich testbed for investigating how animal groups face an overlapping set of coordination challenges under different social and ecological constraints.

Within each study system, we plan to deploy collars incorporating GPS, audio, and Inertial Measurement Unit sensors on all or most members of entire social groups, collecting detailed and simultaneous tracking data on their movements, vocalizations, and behaviors (Figure II.9). Thus far, we have successfully collected such data on multiple meerkat groups over three field seasons in 2017, 2019, and 2021 (Figure II.10), pilot data on five hyenas in 2017, and pilot data on two coatis in 2020.

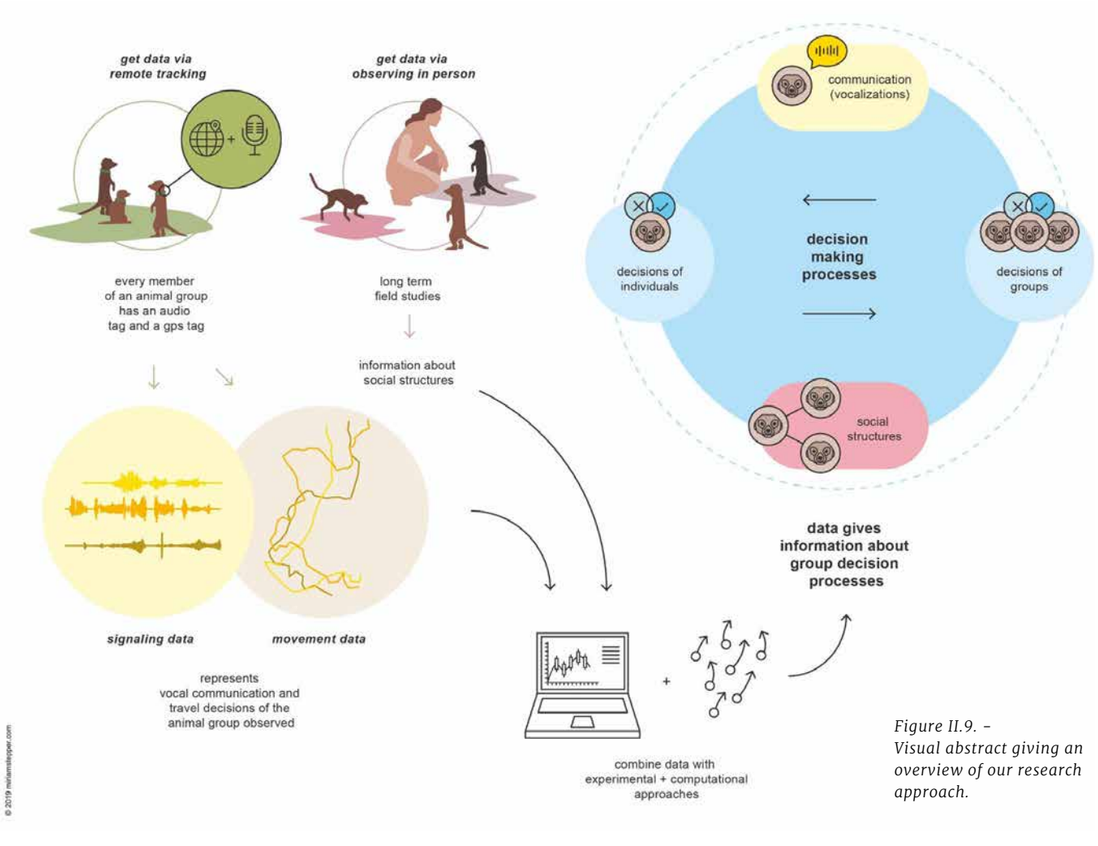



*Figure II.9. – Visual abstract giving an overview of our research approach.*

Initial analyses of the data in meerkats have revealed evidence of outsize influence over decision-making by the dominant female (1), as well as localized call and response dynamics which may play a role in the generation of acoustic "hotspots" promoting group cohesion (2). For fission-fusion groups, we have developed a general framework for characterizing fission-fusion events between pairs of individuals and applied it to our hyena data to show that den usage and daily ranging patterns are sufficient to reproduce observed durations of fission-fusion events and overall social preferences, yet fail to capture the total frequency of fission-fusion events as well as other dynamical features of these interactions (3).

To enable automatic processing of acoustic data, we are developing a convolutional-recurrent neural network-based machine learning pipeline for call detection and classification (4), and are using unsupervised approaches to further explore the vocal repertoires of our study species (5). We have also developed a random forest classifier that can accurately capture basic behavioral states (e.g., resting vs. movement gaits) of hyenas based on accelerometer data (6).

### NETWORK EXPERIMENTS IN HUMAN GROUPS

In parallel with these field-based observational studies of animal groups, we are conducting online network experiments in human groups to investigate how communication network structure affects collective decision-making. Initial results reveal that individuals balance conformity and inertia when making decisions and that this simple rule can give rise to empirically observed patterns at the network level including slower consensus under conflicts of interest that can not be overcome by adding more communication channels (7).

# Future research agenda

Over the next few years, our main aim will be to capitalize on the collaborations and tools we have built during this initial phase to gain insights into the processes of communication and coordination within each study system. In addition to the observational data we are now collecting, future work will incorporate experimental manipulations such as playbacks, conducted while collars are on, to isolate the causal mechanisms governing observed patterns. Ultimately, we would like to understand (i) how individuals integrate spatial and acoustic information to make decisions, (ii) how these decisions are shaped by long-term social relationships within groups, and ultimately (iii) how these interactions give rise to collective outcomes from cohesive movement to collective defense. While our initial investigations will be system-specific, a key longer-term goal is to identify unifying mechanistic principles that operate across multiple study systems, as well as highlighting ways in which systems differ and how these are linked to their specific social and ecological constraints. Toward this end, we have already begun developing several collaborations that will allow us to apply similar methods in additional study systems. The development of this larger collaborative network will enable a broader comparative approach, allowing us to address how the mechanisms of communication and coordination are shaped by the social and ecological environments in which they have evolved.

## REFRENCES

**1** Averly, et al., in prep; **2** Demartsev, et al., in prep; **3** Strauss, et al., in prep; **4** Dhanjal-Adams, et al., in prep; **5** Thomas, et al., in prep; **6** Minasandra, et al., in prep; **7** Gaisbauer et al., in review.

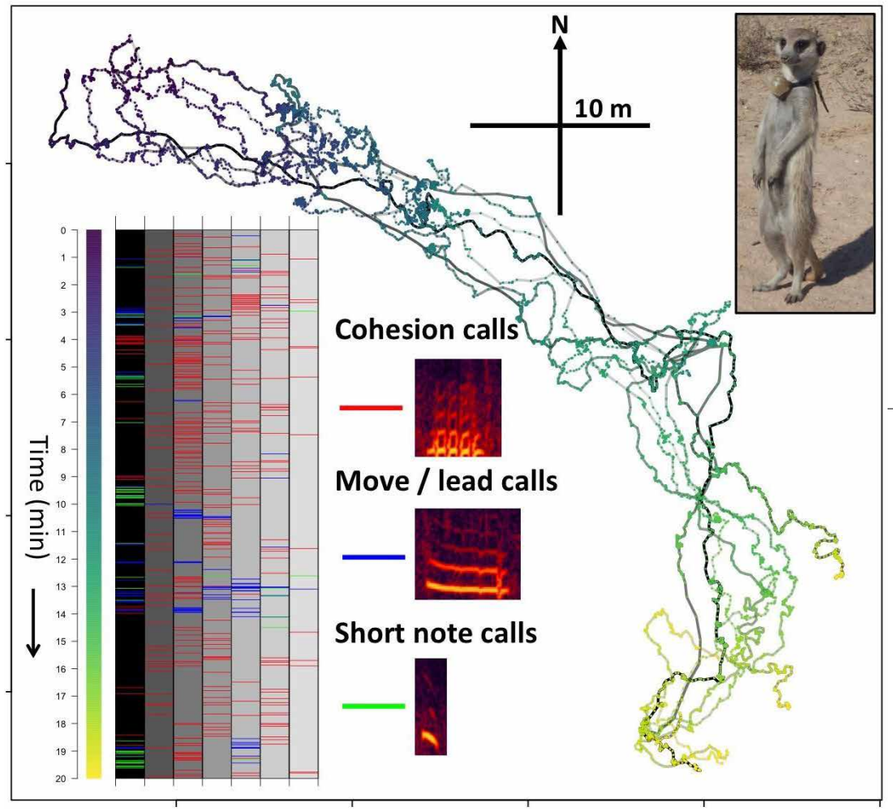



*Figure II.10 –*

*Visualization of combined movement and acoustic data from a meerkat group of seven individuals. Lines show the paths taken by each meerkat over time, with colored points representing the flow of time. Bar plot at bottom left shows the vocalizations given by each individual over time during the same period, highlighting three call types associated with movement coordination (examples shown as spectrogram images). Top right shows a meerkat wearing a combined GPS / acoustic collar.*

# Highlights

## June 2018

Development of an independent Research Group "Communication & Collective Movement" (CoCoMo) at the University of Konstanz, and MPI-AB (since December 2019), enabled by 5-year Gips-Schüle and Zukunftskolleg fellowships.

## March 2019

Lead PI on successful HFSP Research Grant to study communication and coordination across scales in animal societies (with Marta Manser, Kay Holekamp, Ben Hirsch, Marie Roch).

## April 2020

PI on successful CASCB Large Project Grant "The role of communication structure in consensus decision-making in human and animal groups" (with Helge Giese).

## Most important publications

| | | |
|---|---|---|
| 31 | **Strandburg-Peshkin A**, Clutton-Brock T, Manser MB. 2020. Burrow usage patterns and decision-making in meerkat groups. *Behavioral Ecology* 31: 292–302. | *We show using long-term data that meerkat sleep-site decisions are driven by the physical characteristics and spatial configuration of burrows, with predation risk and resource depletion also playing a role. [1 citation]* |
| 27 | **Demartsev V*, Strandburg-Peshkin A***, Ruffner M, Manser M. 2018. Vocal turn-taking in meerkat group calling sessions. *Current Biology* 28: 3661-3668. *equal contributors | *We show that meerkats avoid overlapping one another's calls while sunning and reveal individual-level interactions underlying this pattern, providing evidence of self-organized vocal turn-taking in wild social groups. [13 citations]* |
| 22 | **Strandburg-Peshkin A**, Papageorgiou D, Crofoot MC, Farine DR. 2018. Inferring influence and leadership in moving animal groups. *Philosophical Transactions of the Royal Society* B 373: 20170006. | *We develop a conceptual framework for investigating leadership in social groups and highlight different emerging methods for inferring influence from data on moving animal groups. [21 citations]* |
| 21 | Hughey LF, Hein AM, **Strandburg-Peshkin A**, Jensen F. 2018. Challenges and solutions for studying collective behavior in the wild. *Philosophical Transactions of the Royal Society* B 373: 20170005. | *We give an overview of existing and emerging methods for studying collective behavior in the wild and highlight both opportunities and practical considerations associated with these new methods. [42 citations]* |
| 10 | **Gall GEC, Strandburg-Peshkin A**, Clutton-Brock T, Manser MB. 2017. As dusk falls: collective decisions about the return to sleeping sites in meerkats. *Animal Behaviour* 132: 91-99. | *We show using tracking data that meerkat decisions on the timing of return to their sleep sites occur via a shared decision-making process, and are mediated by urgency-dependent vocalizations. [9 citations]* |

277 *Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

*All publication and citation figures and metrics are based on Web of Sciences on May 31, 2021.*

*Dept./Group members in bold.*

*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*





## Group Leader

# Ariana Strandburg-Peshkin

+ PhD: 2016, Princeton University, with Iain D. Couzin
+ Past positions: Postdoc, University of Zurich (2017-2018), Group Leader, University of Konstanz (since 2018)
+ Joined MPI: 2019 as Group Leader; tenured
+ Selected fellowships, grants & awards: HFSP Long-Term Fellowship (2017), Gips-Schüle Research Group (2018), Zukunftskolleg Fellowship (2018), HFSP Research Grant (2019), CASCB Large Grant (2020)
+ Lifetime publication record: 14 publications, 695 citations, h-index: 10
+ Mean hours of teaching per week during semesters at U KN: 2

## Communication & Collective Movement Group

**10** Number of group members

**6** Number of peer-reviewed papers

**70%** Percentage international group members

**50%** Percentage female group members

**0** Number of finished Doctoral Students

**0 BSc & 0 MSc** Number of finished students

**595,000 €** Third-party funding granted (Top 3 sources: CASCB, HFSP, U KN)

# DEPARTMENT MIGRATION

# DEPARTMENT MIGRATION

## DIRECTOR: MARTIN WIKELSKI

Our aim is to understand the physiology underlying life histories. For example, what distinguishes individuals that migrate from residents? We consider life-history decisions of individuals as biological traits, which can only be understood once Tinbergen's four questions are answered. While the question of (i) phylogeny is generally well resolved for the vertebrates we work with, questions of (ii) physiological mechanisms, (iii) ontogeny, and (iv) selective pressures are poorly understood for wild animals. The answer to all of these questions can only be achieved if the life of animals can be continuously observed in the wild, and their behavior and physiology quantified at the same time. Therefore, 20 years ago, we decided to establish a novel global animal observation system—ICARUS—to provide the basis for answering questions about the physiology of life histories. This has now come to fruition, including a global database for animal movement and behavior—Movebank—and a nascent "Movebank Museum", which provides a living archive for individual animal life histories.

# Research achievements

### GLOBAL ANIMAL OBSERVATION SYSTEM

The original aim of the ICARUS initiative was to broaden our perspective of animal movement from local, isolated issues to the global scale by (i) engineering a novel satellite tracking system and (ii) creating a platform that could unite the global animal ecology community. Our recent achievements provide a powerful endorsement for the ICARUS initiative delivering on its original aim. Our global database for comparing and archiving data on animal movement and behavior has become the international standard for the field of bio-logging today. From a pioneering idea 10 years ago, Movebank has stood the test of time, growing to accommodate more than 2 billion location data points, 5 billion sensor data, and 2 million locations daily from 15 thousand tagged animals. Simultaneously the novel satellite tracking system ICARUS, the first spaceborne IoT (Internet-of-Things, small data package) system, initially thought to be a 5-year project, began operations in March 2021—a perfect 20 years after the idea was born. Currently based on the International Space Station, we are extending ICARUS via novel satellite developments between NASA, ESA, and the DLR. This will stabilize operations until 2045, ensuring that researchers can continue observing individual animals throughout their lifetime across the globe.

### FROM THE FUNDAMENTAL TO THE PRACTICAL

The Migration Department continues to leverage the power of animal tracking to gain insights that range from the fundamental to the practical. Our work deciphering the odors that are responsible for the incredible homeward navigation abilities of pigeons has challenged the conventional wisdom that birds do not use olfaction during navigation (1; Figure II.11). And the first data we collected supporting the potential use of tagged farm animals as an earthquake forecasting system (2; Figure II.12) has enormous implications for communities in disaster-prone areas.

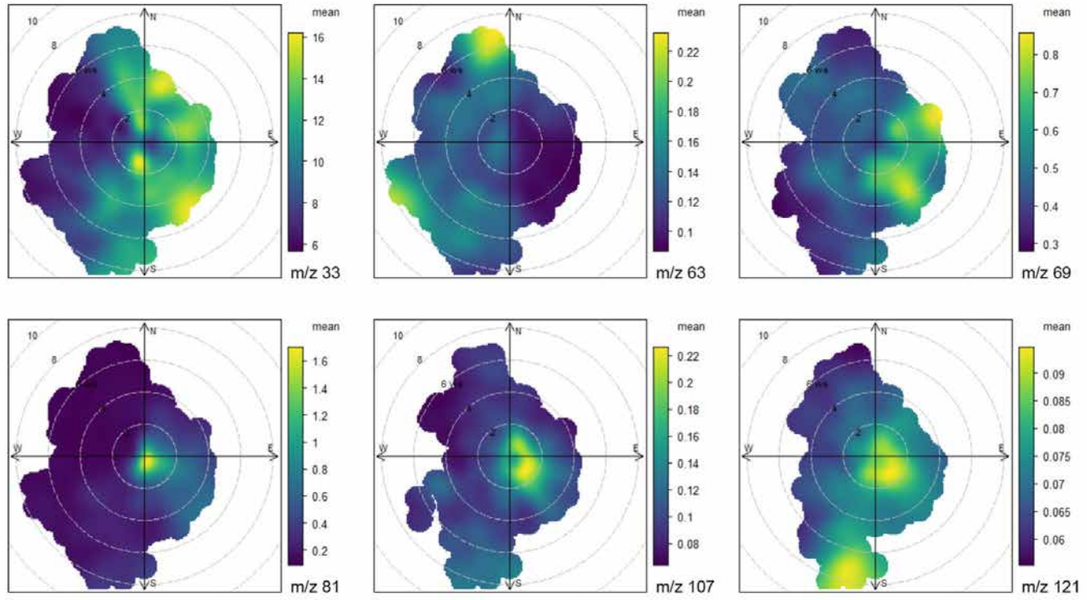



*Figure II.11 –*
*Graphical representation of a spatial odor map, representing environmental odors in Tuscany, Italy (1). Spatial distributions of measured Volatile Organic Compounds (VOCs) identified as: methanol (m/z 33), DiMethylSulfate DMS (m/z 63), isoprene (m/z 69), sum of monoterpenes (m/z 81), sum of xylenes (m/z 107), trimethyl benzene (m/z 121). Mean VOCs (colored scale) are shown as a function of wind direction (angle) and wind speed (radius) at a specific pigeon loft near Pisa, Tuscany. Note that specific odors arrive at the loft from specific angular directions, providing the basis for olfactory imprinting of directional odors.*

Recently, the Department has deliberately been split into smaller, more agile units that are needed to establish a global animal movement tracking and observation system. These units run the spectrum from tracking infrastructure to deep insights into model species to comparative approaches to analytics. Wolfgang Fiedler leads the bird marking and tracking group (a.k.a. Bird Banding 2.0), as well as the Movebank Museum (MoMu). The MoMu is an archive of individual life histories of tracked animals, which has live data feeds to citizen scientists observing animals in the field anywhere, to researchers tagging animals (via the Animal Tracker App), and to Movebank, where all tracks and behaviors of individuals are archived. Jesko Partecke leads a partial migration group studying songbird movement in a particularly feasible study system, the blackbirds, that also allows for genomic analysis and captive breeding experiments. Another migration model system, the European white stork, is now intensively studied by an independent group around Andrea Flack. A comparative movement group with deliberately innovative methods and approaches is headed by Dina Dechmann, studying the importance of seasonal changes in resource abundances which drive most migrations, but also many other seasonal changes in animal ecology. The necessary analytics in animal movement are developed by Kamran Safi and his team, who also established the global AniMove program.

The in- and outreach of ideas is conducted by the MaxCine group headed by Babette Eid, which is now being transferred into a central role at the Institute (page 162). MaxCine, which operates in the space between science, art, and education, is unique within the MPG and extends outreach models Wikelski witnessed at several US institutions.

## Future research agenda

Our aim is to demonstrate the power of deep behavioral and life history knowledge, including movement and behavior of individuals throughout their lifetimes, in key long-term ecological systems. The ICARUS system, with its novel technology and new global ways to collaborate, has delivered the means for achieving this ambition. We established more than 30 ICARUS projects within Russia, and a total of over 100 projects around the world, to track individual life histories of animals. For example, we aim to understand why certain seabird populations such as the sooty terns on Ascension Island in the Atlantic have nine-month breeding cycles, while most other populations of the same species exert regular annual (12 months) cycles. Similarly, we try to understand the ontogeny of migration and navigation in Eurasian cuckoos, tracking young and adult cuckoos from populations ranging from Spain to Kamchatka. A particular future focus also lies in tracking ecosystem services and disease dynamics in frugivores, from neotropical oilbirds to African and Asian fruit bats. For this, we have already perfected the tracking system in African straw-colored fruit bats over the past decade. Another innovative new tracking area is individual insect migration, where we helped to establish an Insect Migration and Navigation study group (our former Marie-Curie fellow Myles Menz), now located in Australia.

The new global community of animal movement groups is also enabling global syntheses such as a study of the multitude of global ecological effects of the "Anthropause" (a term we coined; 3), the Arctic Animal Movement Archive (AAMA; 4) or an envisaged Sub-Saharan Movement Archive (SSMA).

We also received support to continue the study of interacting collectives of animals in the wild to determine whether information from these collectives can be used to study how animals can protect other (endangered) animals, such as African large mammals potentially protecting rhinos through fear behavior towards poaching intrusions. Through these studies, we will understand collective behavior in the wild and at the same time gain important practical applications for conservation management. The latter is now often demanded as a basis for allowing particular studies on wild animals by management authorities. We call this "application enables insight", as a corollary to the general MPG theme of "insight precedes application".

**REFRENCES**

**1** Zannoni et al. 2020. *Scientific Reports* 10: 15879; **2** Wikelski, et al. 2020. *Ethology* 126: 931-941; **3** Rutz, et al. 2020. *Nature Ecology & Evolution* 4: 1156–1159; **4** Davidson, et al. 2020. *Science* 370: 712-715.

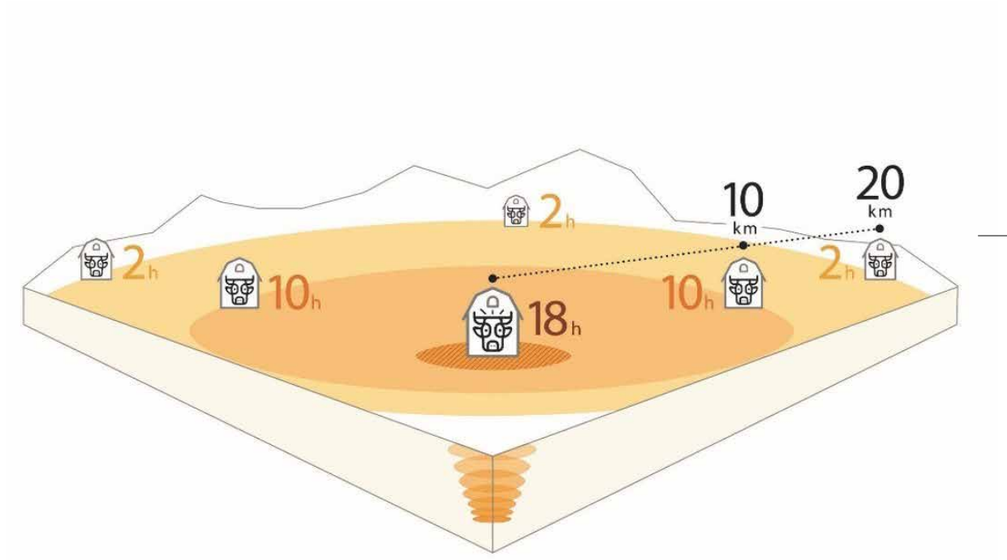



*Figure II.12 -*
*A potential test setup for an earthquake-forecast-by-animals scenario (2). We have started to set up animal activity monitoring sites across a landscape (e.g., the Italian Abruzzo mountains). The preparatory processes in the Earth's crust preceding an imminent earthquake might be perceived by animals. If true, the animals on the central farm situated above the hypocenter should show activity ca. 18 hr ahead of the earthquake, but no other farm animals should show warning signs at this early time. Then, 8 hr later, farm animals at 10 km distance from the central farm should show warning signs. Another 8 hr later animals at farms 20 km away from the central farm should show warning signs. If correct, this would indicate an earthquake is imminent within the next 2 hr.*

## Highlights

### July 2020

First field test of emergent properties of interacting collectives of animals that show novel environmental sensing properties (2). Field tests of earthquake detection using animal collectives in Italy and Chile, and tests of volcanic eruptions in SE Asia and Sicily. Receiving patents for these findings in Europe and the US.

### October 2020

Establishing avian olfaction as an important sense during navigational and foraging tasks (1). Creating the first olfactory maps of a landscape (Tuscany) and testing its influence on homing in pigeons.

### March 2021

Development of ICARUS global animal observation system, the first ground-to-space IoT (Internet of Things) CDMA (code-division-multiple-access) system. ICARUS tracking tags are mass-produced and applied in many long-term ecological study systems around the world.

## Most important publications


**Wikelski M, Quetting M**, Cheng Y, Fiedler W, Flack A, Gagliardo A, Salas R, Zannoni N, Williams J. 2021. Smell of green leaf volatiles attracts white storks to freshly cut meadows. *Scientific Reports* 11: 12912.

*A simple, but powerful observation and experiment showing how important smell is for foraging movements in birds. [0 citations]*


**Wikelski M, Mueller U**, Scocco P, Catorci A, Desinov LV, Belyaev MY, Keim D, Pohlmeier W, Fechteler G, Mai PM. 2020. Potential short-term earthquake forecasting by farm animal monitoring. *Ethology* 126: 931-941.

*First publication showing the potential of interacting animal collectives to novel environmental parameters at heretofore unknown levels, such as precursors of earthquakes. We do not yet understand this system mechanistically but can read it like a "black box" similar to a bloodhound following a trail. [2 citations]*

**Wikelski M, Müller U**, Heidrich WA, Kümmeth FX. 2020. Disaster alert mediation using nature. *US Patent* US10877179B2.

*Patent on the emergent sensing of interacting collectives of animals. Akin to "behavioral bionics".*


Zannoni N, **Wikelski M**, Gagliardo A, Raza A, Kramer S, Seghetti C, Wang N, Edtbauer A, Williams J. 2020. Identifying volatile organic compounds used for olfactory navigation by homing pigeons. *Scientific Reports* 10: 15879.

*We create a landscape-scale map of environmental odors and show how birds could use this information for navigation. [2 citations]*


Kays R, McShea WJ, **Wikelski M.** 2020. Born-digital biodiversity data: Millions and billions. *Diversity and Distributions* 26: 644-648.

*A call to action for preserving the digital biodiversity data on animal movements and camera traps for eternity. [6 citations]*


*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

*All publication and citation figures and metrics are based on Web of Sciences on May 31, 2021.*

*Dept./Group members in bold.*

*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*





## Max Planck Director

# Martin Wikelski

+ PhD: 1994, University of Bielefeld, with Fritz Trillmich
+ Past positions: Research Associate, University of Washington (1995-1998), Postdoc, Smithsonian Tropical Research Institute (1996-1998), Assistant Professor, University of Illinois at Urbana-Champaign (1998-2000), Assistant (2000-2005) and Associate Professor, University of Princeton (2005-2008), Full Professor (2008-2016) and Honorary Professor (since 2016), University of Konstanz
+ Joined MPI: 2008 as Director
+ Selected fellowships, grants & awards: Niko-Tinbergen Laureate (1998), Bartholomew Laureate (2000), National Geographic Society 'Emerging Explorer' (2008) and 'Adventurer of the Year' (2010), elected member of the Leopoldina (2014), Max Planck Research Award (2016), Order of Merit of the State of Baden-Württemberg (2021)
+ Lifetime publication record: 351 publications, 18,674 citations, h-index: 75
+ Mean hours of teaching per week during semesters at U KN: 3

## Department Migration

**16**
Number of group members

**159**
Number of peer-reviewed papers

**25%**
Percentage international group members

**38%**
Percentage female group members

**1**
Number of finished Doctoral Students

**1 BSc & 3 MSc**
Number of finished students

**4,401,000 €**
Third-party funding granted (Top 3 sources: US Office of Naval Research, European Union, CASCB)

# RESEARCH GROUP EPHEMERAL RESOURCE ADAPTATIONS

## GROUP LEADER: DINA DECHMANN

The focus of research at the Ephemeral Resource Adaptations Group is on how animals adapt to ephemeral resource availability. By studying small, high-metabolic mammals that function at the energetic knife's edge, we elucidate the behavioral, physiological, and morphological strategies that allow them to overcome changes and bottlenecks in resources, especially in food availability. In a broadly collaborative approach, we aim to question accepted rules in ecology and evolution and use our animal models to show how they push the boundaries of what is thought possible.

# Research achievements

### SOCIAL INFORMATION TRANSFER AND RESOURCE AVAILABILITY

A long-term research interest in our Group is how group structure, stability, and ultimately the evolution of sociality may be linked to resource availability through increased foraging efficiency via social information transfer (1, 2). In the past four years, we have been developing a framework for social information use based on the distribution of resources in the landscape (Figure II.13; 3, 4). We have combined experiments with targeted fieldwork to support and quantify how niche adaptation, seasonal energetic pressure, and behavioral adaptations are linked to resource ephemerality (5-8). Ongoing work is taking us deeper into directly addressing targeted questions regarding the link between the resource landscape and the occurrence of social information use in flexible and obligate social foragers by incorporating seasonal environmental change as well as the life-history stage.

### NOVEL ENERGY-SAVING STRATEGIES IN SMALL ANIMALS

One important aspect we investigate is how our small study animals, with their extraordinarily high metabolisms, balance their daily and seasonal energy budgets. Here, we have uncovered novel energy-saving strategies in bats and shrews. Using new approaches, we show that both tropical and temperate zone bats can save large amounts of energy by lowering their heart rate independently from body temperature (9-11). Leveraging tracking technology has further allowed us to crucially expand knowledge on bat flight, a highly energetically expensive mode of locomotion. We show that bats may use mechanisms such as energy provided by the landscape, which allows them to spend less energy than currently assumed (12-14).

A different strategy is used by the common shrew, the mammal with the highest measured metabolism. Here, we find that relative oxygen consumption does not differ between winter and summer despite a difference of over 30°C in ambient temperatures. During the colder months, shrews instead reduce their body size, which in turn leads to absolute energy savings in winter (15), a process we are currently further investigating using genomics, proteomics, and experimental approaches.

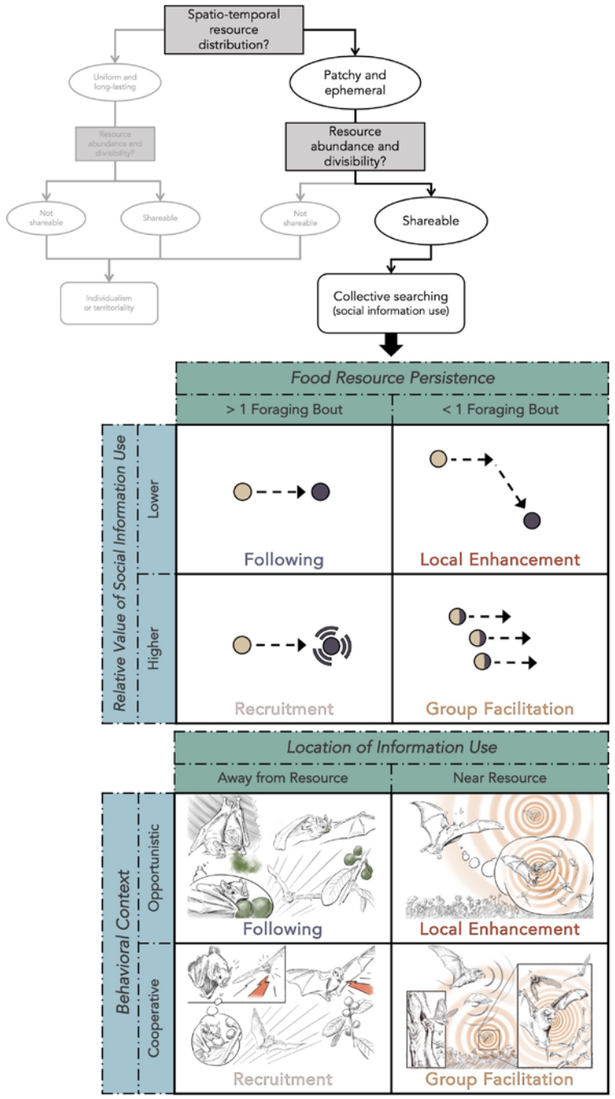



*Figure II.13 – Framework for predicting social information use based on resource structure (Kohles et al. in prep.)*

### DEHNEL'S PHENOMENON AND BRAIN EVOLUTION

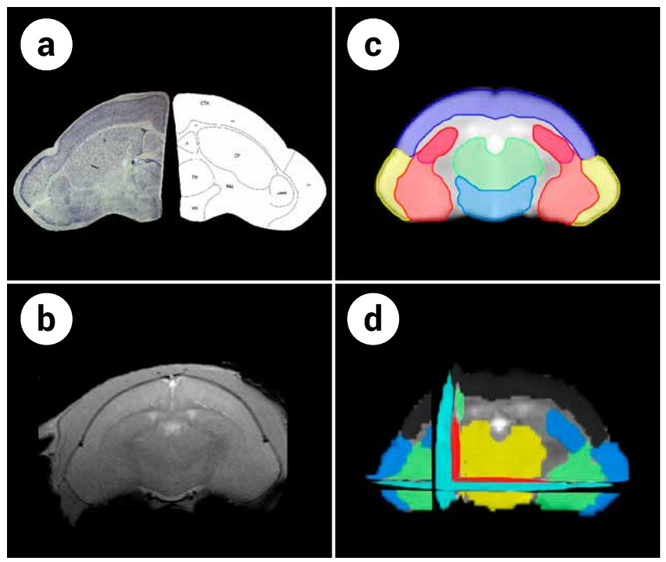
This work sets the scene for another focus of our research, which is to explore Dehnel's Phenomenon: the seasonal, reversible size change of the individual. Dehnel's Phenomenon is known to include changes in the skull and brain in shrews, and as we were recently able to show, mustelids (16, 17) and moles (in prep.). This unique case of adaptation to seasonal resource changes provides a singular opportunity to integrate energetics, physiology, and (brain) morphology. We were the first to document this phenomenon in the individual (18) and our position at the forefront of this research helped us gain an HFSP Research Grant in 2019 (19-21). With international collaborators, we plan to explore the enormous potential of this phenomenon, including promising benefits for human health. We have now repeatedly scanned shrews throughout their lifetime using state-of-the-art MRI technology, documenting changes in overall brain size as well as the size of brain regions in living individuals (Figure II.14). At the same time, our continued fascination with this crucial but energetically expensive organ has resulted in a large body of comparative work investigating the link between brain size and the size of the ecological niche (22, 23).

# Future research agenda

A large part of our research capacity in the next years will continue to be taken up by the HFSP-funded collaborative project on seasonal brain size changes in the common shrew. Over the next years, we will follow cohorts of shrews as they go through the size change, which takes a full year to complete. We will characterize the neurophysiology of the cycle with a special focus on adult neurogenesis. We will pioneer in vivo MRI-imaging in combination with targeted behavioral experiments with the same individuals, to understand the cognitive compromises and energetic trade-offs resulting from the brain size reduction. This collaborative project builds on our previous work and addresses for the first time the multiple scales—from the morphology and histology of the cycle and deep-time evolution to molecular pathways—involved in this unique adaptation over the shrews' entire lifespan.

Sensing the changing resource landscape, and incorporating a broad array of information types to make the best decision under current circumstances, is a task animals face every day. Bats use social information transfer as a means to efficiently find ephemeral food sources, and understanding how this evolved is another research focus in our Group. We have been pivotal in pushing forward a more nuanced understanding of bat flight, something that has only been possible with the miniaturized technologies developed and employed at the MPI-AB. In the coming years, we will compare adaptations across geographical and seasonal resource gradients and along the life cycle in several bat species in Europe, Central America, and Africa using novel technology such as miniaturized heart rate transmitters and GPS tracking, especially ICARUS.

Combining data on flight costs, changes in diet availability and quality, and other physiological and behavioral adaptations will help us understand how these small, high-metabolic but highly successful mammals (with over 1,400 species) balance their daily energy budget. In the next few years, we intend to experimentally investigate the role of Highly Unsaturated Fatty Acids and Polyunsaturated Fatty Acids on the speed and efficiency of energy mobilization during foraging and migration as well as reproduction. Tracking of entire groups of bats will let us tie in the role of social information transfer about their ephemeral food resources, and assess fitness consequences as well as effects on lifespan variation and the evolution of sociality.



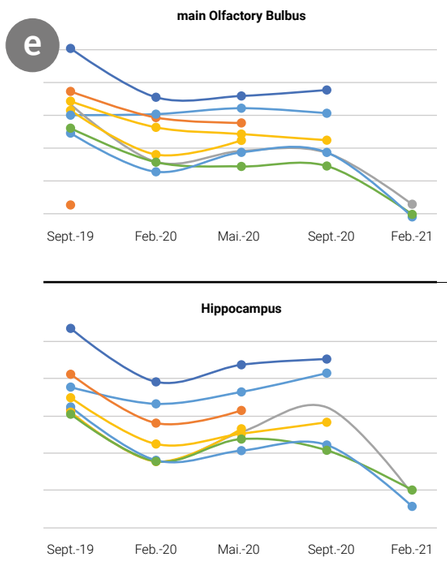





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*Figure II.14 - State-of-the-art MRI imaging goes beyond A) conventional section staining. Instead, we used methods such as B) repeatedly scanning the living brain; creating a C) three-dimensional representation of the brain; D) directional fiber tracking using DTI; and E) tracking individual size changes in major brain regions such as the olfactory bulb or the hippocampus.*

# Highlights

## November 2017

Documenting massive individual reversible changes in brain size for the first time, with repeated x-rays and recently with repeated in-vivo MRI images describing also correlated changes in brain architecture.

## December 2018

Dechmann's habilitation at the University of Konstanz and appointment as Group Leader at the MPI-AB (August 2020).

## March 2019

Being awarded a Human Frontiers Science Program Research Grant for the project "Regrowing the brain - evolution and mechanisms of seasonal reversible size changes in a mammal."

## Most important publications

| | | |
|---|---|---|
| 264 | Wilkinson GS, Adams DM, Arnold B, Ball H, Carter G, Cooper L, **Dechmann DKN**, Devanna P, Fasel N, Galazyuk AV, Gunther L, Haghani A, **Hurme E**, Jones G, Knornschild M, Lattenkamp EZ, Lu A, Mayer F, Medellin R, Nagy M, Reinhardt J, Teeling E, Vernes SC, Zamora D, Zoller J, Horvath S. 2021. DNA methylation predicts age and provides insight into exceptional longevity of bats. *Nature Communications* 12: 1615 | *Establishing a method to age bats using three of our focal species. This method has led to additional publications in our Group and will be the foundation for many more. [4 citations]* |
| 164 | **O'Mara MT**, AmorimF, Scacco M, McCracken G, Safi K, Mata V, Tomé R, Swartz S, Wikelski M, Beja P, Rebelo H, **Dechmann DKN**. 2021. Bats use topography and nocturnal updrafts to fly high and fast. *Current Biology* 31: 1311-1316. | *High-resolution GPS data and a novel modeling approach shows, for the first time, that bats use energy generated by the landscape. This is an important step towards truly understanding the cost of bat flight. [1 citation]* |
| 116 | van Toor ML, **O'Mara MT, Abedi-Lartey M**, Wikelski M, **Fahr J, Dechmann DKN.** 2019. Linking colony size with quantitative estimates of ecosystem services of African fruit bats. *Current Biology* 29: R225-R240. | *Quantifying ecosystem services and reforestation by arguably the most numerous, but declining, mammal of Africa. [14 citations]* |
| 438 | **Lazaro J, Dechmann DKN, LaPoint S**, Wikelski M, Hertel M. 2017. Profound reversible seasonal changes of individual skull size in a mammal. *Current Biology* 27: R1106-R1107. | *The first documentation of reversible brain size changes by 20% and more with massive implications for applied research. Results are now confirmed by MRI (unpublished, Figure 2). [16 citations]* |
| 71 | **O'Mara TM**, Wikelski M, Voigt CC, ter Maat A, Pollock HS, Burness G, Desantis LM, **Dechmann DKN.** 2017. Cyclic bouts of extreme bradycardia counteract the high metabolism of frugivorous bats. *eLife* 6: e26686. | *The first of a series of papers showing how bats can independently lower heart rate to save large amounts of energy at high body temperatures. [26 citations]* |

*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

*All publication and citation figures and metrics are based on Web of Sciences on May 31, 2021.*

*Dept./Group members in bold.*

*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*



## Group Leader

# Dina Dechmann

+ PhD: 2005, University of Zürich, with Hans-Peter Lipp
+ Past positions: Postdoc, University of Zurich (2006), Postdoc, Leibniz Institute for Zoo and Wildlife Research Berlin (2007-2008), Research Scientist, University of Konstanz (2008-2012)
+ Joined MPI: 2012 as Group Leader; tenured
+ Selected fellowships, grants & awards: DFG Research Grant (2011), HFSP Program Grant (2019)
+ Lifetime publication record: 88 publications, 1,714 citations, h-index: 23
+ Mean hours of teaching per week during semesters at U KN: 4

## Ephemeral Resource Adaptations Group

**7**
Number of group members

**52**
Number of peer-reviewd papers

**86%**
Percentage international group members

**86%**
Percentage female group members

**1**
Number of finished Doctoral Students

**2 BSc & 3 MSc**
Number of finished students

**689,000 €**
Third-party funding granted (HFSP, CASCB)

# RESEARCH GROUP BIRD MOVEMENTS AND ANIMAL MARKING

## GROUP LEADER: WOLFGANG FIEDLER

The Bird Movements and Animal Marking Group seeks to understand the phenology of bird movements and their consequences for the bird and the environment, with a focus on white storks, red kites, and mallards as model species. A key part of this effort lies in running the Center for Animal Marking. This core facility brings together proven structures and strategies from conventional bird ringing with the new options and challenges of using electronic devices on wild animals.

## Research achievements

### THE CENTER FOR ANIMAL MARKING (CAM)

Also known as "Vogelwarte Radolfzell", CAM provides support, training, and data management for scientific bird ringing in southern Germany and Berlin. We cooperate closely with 388 trained and skilled volunteer bird ringers working on their own studies or contributing to larger research projects. Every year, around 50,000 birds are marked with rings and around 15,000 ringed birds are recovered. During the last decade, the former bird ringing center has been transformed into a competence center for the use of conventional as well as electronic tracking devices; trapping technology; the application of tools like Movebank or the Animal Tracker; and the development of best practices for logger management and logger retrieval from abroad, including the identification of mortality reasons (Figure II.15).

### LIFETIME TRACKING OF WHITE STORKS

The white stork is a widely used model species for the study of migrating birds. Since 2013, local groups and institutes have cooperated to equip almost 500 white stork nestlings from 12 different regions with GPS loggers to track them through their lives. The results, which enable us to describe the migration patterns of this species in high accuracy from almost all parts of its range, have unleashed a range of novel insights. These include detailed analyses on early life development and benefits of different migration and wintering strategies (e.g., 1, 2, 3 in cooperation with Ran Nathan, Uni of Jerusalem). Importantly, they resulted in the ground-breaking finding in *Science*, led by the Group of Andrea Flack, that social interaction plays a key role for younger storks on their first migration (4).

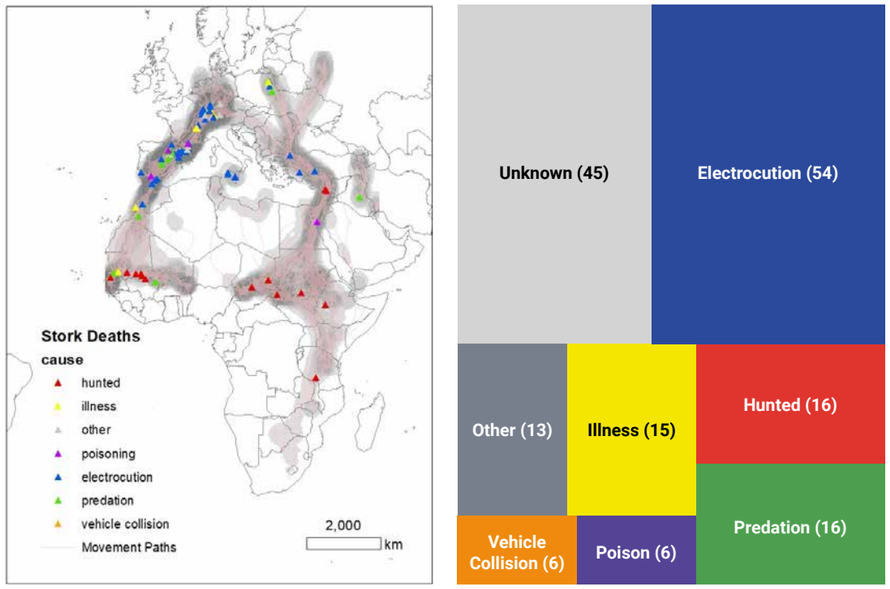


*Figure II.15 – Cause of mortality of 171 tracked white storks where acceleration and GPS data of the transmitters indicate that the bird has died.*

### SMALL- AND LARGE-SCALE MOVEMENTS OF RED KITES AND HONEY BUZZARDS

As strictly protected species, red kites and honey buzzards are key points in discussions on the conservation implications of wind power plants. In 2018 we launched a tracking study, funded by the State of Baden-Württemberg, to bring clarity to the question of whether predicting flight behavior can help reduce the collision risk of raptors like kites and buzzards at wind power plants. Preliminary results, which detail these flight behaviors, show a very high variation of flight activities under different weather conditions and a high intra-individual variation in the size of home ranges (Figure II.16) whereas the intra-individual home ranges are very uniform between years.

### EUROPEAN-AFRICAN BIRD MIGRATION ATLAS

In this joint project of the European Union for Bird Ringing and the Bonn Convention of Migratory Species, the present knowledge of bird migration in the European-African flyway system, connectivities, recent changes, and threats will be compiled for the magnitude of European bird species. Our part in this project is a work package that aims to harmonize the knowledge gained by electronic devices with that based on classical bird ringing (5).

## Future research agenda

In our research on bird movements, we plan to bring into focus the decisions and strategies made by the individual, to elucidate the reasons for these decisions and the consequences they have. Our focus marks a departure from research in the past when variability was often treated as a disturbing element in models built on pooled data of many individuals. This approach of pooling individuals, however, fails to appreciate that selection acts on individuals and not on population averages. Yet for a long time, studying individual decisions presented a technical challenge, requiring many individuals of the same taxon and population to be followed, ideally over their whole lifetime. Now, with our ability to collect continuously high rates of movement (and additional sensor) data of single individuals, the individual variability of strategies and decisions can be rigorously studied for the first time. We will therefore continue long-term tracking activities based on cooperation with other Groups at the MPI-AB and elsewhere. Our systems will be predominantly white storks, red kites, common buzzards, and golden eagles in Europe; mallards in Europe and Asia; and vultures in South

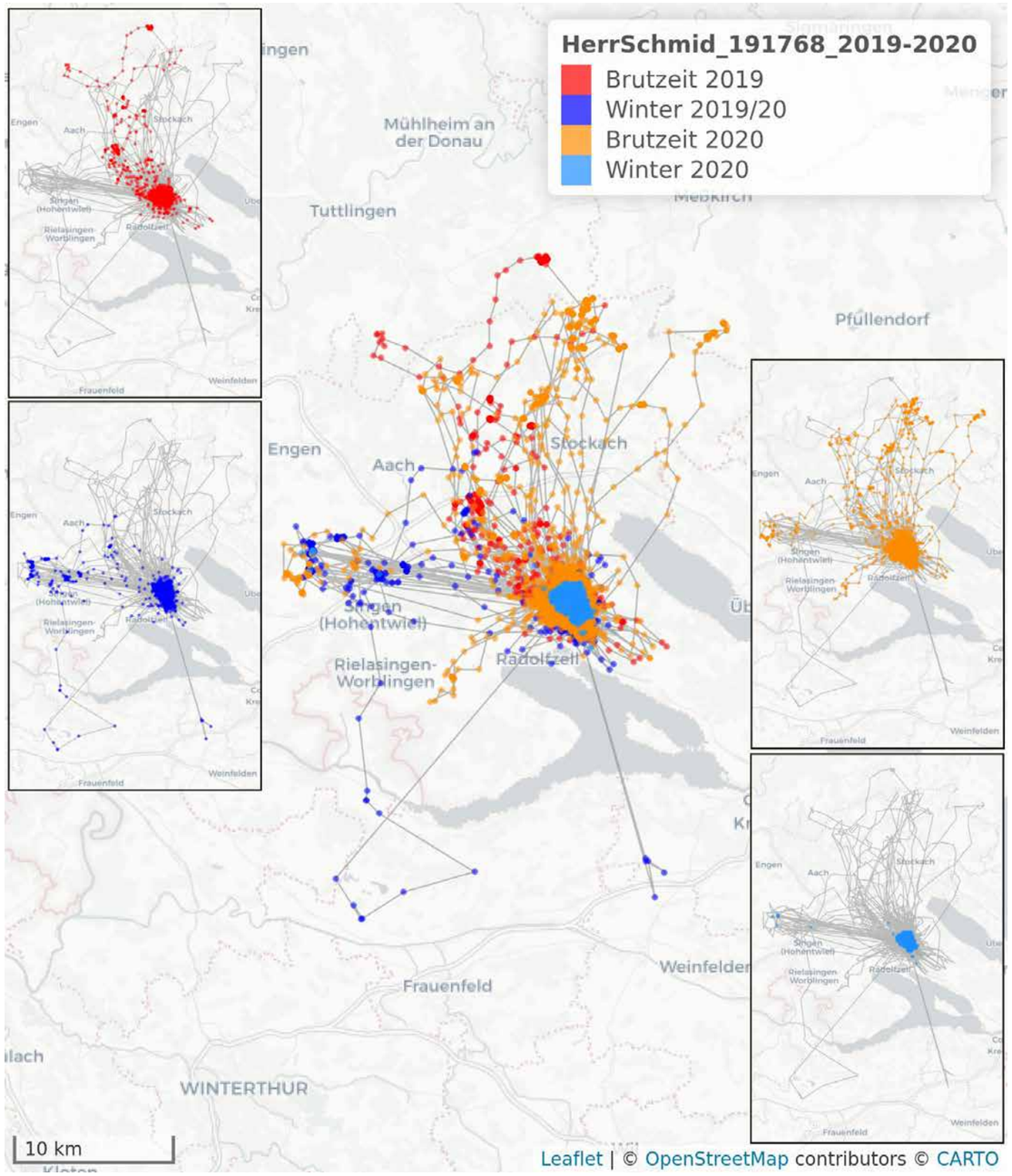


*Figure II.16 –*
*Movements of GPS-tracked red kite "HerrSchmid" in two seasons during breeding (red and orange) and during winter (dark and light blue). This bird breeds close to the MPI-AB in Radolfzell and is one of the approximately 15% of non-migrating red kites in Baden-Württemberg. Remarkably, the range during the breeding season is larger than the winter range.*

Africa. We also plan to study long-distance migrating songbirds, as soon as methods allow the collection of data in higher resolution.

For our white stork project, in particular, we will harness the first decade of data from the GPS tracking project started in 2013. This, combined with the available excellent ring recovery data, will power future studies into how white storks change migration strategies, and what that means for connectivities to wintering grounds.

We intend to further develop the CAM into a service facility that unifies proven structures and strategies from conventional bird ringing with the new options and challenges of using electronic devices on wild animals. Since its founding almost 80 years ago, the CAM has maintained its place at the forefront of animal marking in southern Germany through continually developing core operations, from quality training to rigorous ethical standards to a data and tech infrastructure that keeps pace with modern times. We will continue in this tradition by investing in our dedicated personnel and yoking classical methods with the state of the art to ensure that CAM remains an essential part of animal marking in Germany into the future.

**REFRENCES**

**1** Rotics et al. 2017. *Animal Behaviour* 126: 79-88; **2** Rotics et al. 2018. *Journal of Animal Ecology* 87: 1627-1638; **3** Fandos et al. 2020. *Proceedings of the Royal Society* B 287: 20201799. **4** Flack et al. 2018. *Science 360*: 911-914. **5** Baillie et al. 2018. *Lifecycle Autumn 2018*: 2.

# Highlights

## September 2019

Fiedler was elected President of the German Ornithologists' Society (DO-G).

## 2019–2020

We collected the first four complete high-resolution tracks of the wintering behavior of the rare and cryptic German honey buzzards in Western Africa.

## January 2020

Our paper was published about the first heart rate data collected from migrating storks with implanted heart rate loggers between NE Poland and Romania as well as Israel.

## Most important publications

| | | |
|---|---|---|
| 13 | Flack A, Schaeffer PJ, Taylor JRE, Müller I, Wikelski M, **Fiedler W.** 2020. Daily energy expenditure in white storks is lower after fledging than in the nest. *Journal of Experimental Biology* 223: jeb219337. | *The first paper on heart rate loggers where the veterinarian Inge Müller and Wolfgang Fiedler successfully established the implanting protocol in wild white stork nestlings. [1 citation]* |
| 13 | Blas J, **Reyes S**, Flack A, Torres-Medina F, Sergio F, Wikelski M, **Fiedler W.** 2020. Overland and oversea migration of white storks through the water barriers of the straits of Gibraltar. *Scientific Reports* 10: 20760. | *One example of the many detailed aspects that can be investigated based on our unique white stork tracking dataset. [0 citation]* |
| 24 | Kleyheeg E, **Fiedler W**, Safi K, Waldenström J, Wikelski M, van Toor ML. 2019. A comprehensive model for the quantitative estimation of seed dispersal by migratory mallards. *Frontiers in Ecology and Evolution* 7: 40. | *The outcome of a cooperation project in mallard tracking that can form the base for further work on pathogen dispersal through waterbirds. [11 citations]* |
| 39 | Nagy M, Couzin ID, **Fiedler W**, Wikelski M, Flack A. 2018. Synchronization, coordination and collective sensing during thermalling flight of freely migrating white storks. *Philosophical Transactions of the Royal Society* B 373: 20170011. | *This paper takes a novel approach by examining fine-scale motion and sociality in white storks during migration. [18 citations]* |
| 5 | Sherub S, **Fiedler W**, Duriez O, Wikelski M. 2017. Bio-logging, new technologies to study conservation physiology on the move: A case study on annual survival of Himalayan vultures. *Journal of Comparative Physiology* A 203: 6-7. | *An approach that aims to bring together tracking technology, physiology, and conservation. [7 citations]* |

*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

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*Dept./Group members in bold.*

*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

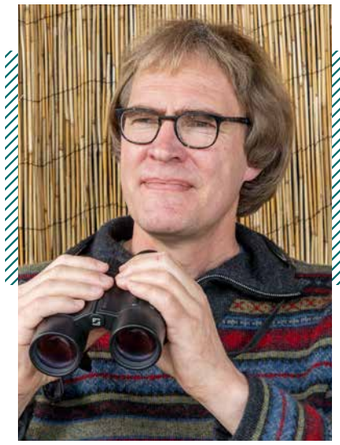
*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*





## Group Leader

# Wolfgang Fiedler



- PhD: 1997, MPI Radolfzell with Peter Berthold and Klaus Schmidt-König
- Past positions: Postdoc, MPI Radolfzell (1998-2004), Interims Head, MPI Radolfzell (2005-2008)
- Joined MPI: 1993 as MSc student
- Group Leader: since 2008; tenured
- Selected fellowships, grants & awards: President of the German Ornithologists' Society (since 2019)
- Lifetime publication record: 77 publications, 2,410 citations, h-index: 27
- Mean hours of teaching per week during semesters at U KN: 1

## Bird Movements and Animal Marking Group

**2**
Number of group members

**27**
Number of peer-reviewed papers

**0%**
Percentage international group members

**50%**
Percentage female group members

**0**
Number of finished Doctoral Students

**1 BSc & 0 MSc**
Number of finished students

**135,000 €**
Third-party funding granted (State government, German foundations)

# RESEARCH GROUP COLLECTIVE MIGRATION

**GROUP LEADER: ANDREA FLACK**

Many animals can obtain information by observing the behavior of others. Using social information can reduce costs of trial-and-error experiences and may therefore be essential during many crucial lifetime decisions, like, for example, during migration. The social aspects of migration, however, have received very limited scientific attention so far. The research program of the Collective Migration Group aims at decoding the impact of the social environment on the movement decisions of migrating birds by exploring decision-making processes, emergent behavioral patterns, and their long-term ecological and evolutionary implications.

## Research achievements

The white stork is a common long-distance social migrant that relies on soaring-gliding flight. Most empirical studies on soaring flight explore the link between individual features and soaring performance. Yet, individuals may perform very differently depending on their social environment. In a previous study, we found that older, more experienced white storks fly faster with lower flight costs than juvenile birds (1). This indicates that group composition is essential for successfully reducing movement costs. But what determines the composition and function of migrating flocks? During our past years, we were able to record at an unforeseen spatio-temporal resolution the migration of storks to describe the patterns and costs of individual and collective soaring migration (2-4). In collaboration with computational ecologists, meteorologists, and remote sensers, we have now developed methods to map the landscape that the storks fly through at a fine-scale by using environmental data, satellite images, and/or the stork movements themselves (5-7). We have also succeeded in obtaining heart rate recordings of freely-migrating white storks (8) to measure directly the movement costs of migration.

In a previous study, we also uncovered the large variation in the migratory decisions of white storks from different populations (3). The movement strategies of juveniles ranged from fully migratory in Europe, with birds traveling along the well-described eastern or western routes, to year-round residency in Uzbekistan. These different behavioral phenotypes provide a natural setup for examining the inherited and social features of migratory behavior.

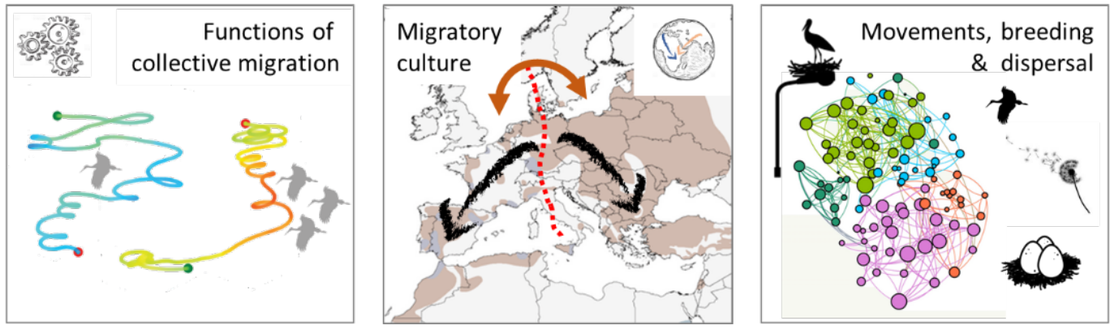



*Figure II.17 -*
*Schematic representation of example studies of the three research lines. (left) Functions of collective migration: comparison of soaring performance (color of flight tracks) of groups of different compositions. (middle) Migratory culture: experiment to test whether adult storks rely on either social information or learned migratory behavior when displaced in areas on the other side of the migratory divide (red dashed line). (right) Movement, breeding & dispersal: finally, use of long-term monitoring data of breeding behavior to explore the connection between dispersal, sociality, movement, and population processes.*

## Future research agenda

The ongoing and future work of our Group can be divided into three broad directions (Figure II.17). First, we elucidate the functions and mechanisms of collective migration using an experimental approach. Second, we focus on the evolutionary ecology of collective migration by examining migratory culture. Finally, by integrating fine-scale movement data with long-term monitoring data of breeding behavior, we are exploring the connection between dispersal, sociality, movement, and population processes.

### MECHANISMS OF COLLECTIVE MIGRATION

With the different tracking and analytical methods, we can now clearly characterize a stork's phenotype, movements, costs, and environment, enabling us to describe precisely the relationship between individual phenotypes and soaring performance. Over the coming years, we will expand these studies by exploring how an individual's social surroundings alter its flight performance. The established bio-logging techniques, including high-resolution GPS, accelerometers, magnetometers, heart rate loggers, and onboard cameras, will provide detailed measures on the birds' dynamic movements, their relative positions, and orientation to each other, and their physiological responses. By conducting experimental studies under ecologically and evolutionarily relevant field conditions that, for example, involve releasing groups of storks after all free-living migrating white storks have left the region (so-called delayed releases, Figure II.18), we can examine the effect of group size and composition by altering the properties of the release groups, thereby really exploring the mechanisms underlying collective migration in large soaring birds.

### MIGRATORY CULTURE

For storks, the social surroundings are essential not only for detecting favorable flight conditions but also for choosing migratory routes. However, despite tracking the movements of storks for many years, the longer-term consequences of their movement decisions (e.g., memory formation) are still relatively unknown. Although we know that route choice in storks is influenced by social factors, the questions of whether they exhibit this kind of cross-generational persistence (i.e., migratory culture), and, if so, how it is influenced by their social environment, have not been studied in detail. Similarly, it is not known

whether and how storks synchronize their movements during their spring migration when traveling with a largely unrelated, unknown community; or how the experiences (social and environmental) during the different migration bouts (autumn vs. spring) are influencing the development of route memories. To reveal how much of an individual's migratory decisions are influenced by genetic, environmental, and social factors, we are planning to conduct translocation and cross-fostering experiments between individuals from different populations. These experiments will allow us to investigate the phenotypic plasticity of migratory traits under different environmental and social conditions.

## DISPERSAL, SOCIALITY, MOVEMENT, AND POPULATION

Finally, how social and environmental factors influence the movement decisions of dispersing individuals is a poorly studied aspect of bird migration. The combination of long-term breeding monitoring with high-resolution tracking of individuals over multiple years now provides us with a unique opportunity to test different hypotheses regarding the dispersal of white storks. Local densities, territoriality, or differences in behavioral phenotypes may influence an individual's decisions to leave or settle at a given patch. To test this, we are planning to examine the breeding success of stork nests with varying densities over the past 10–20 years.

So far, we have successfully explored many important aspects of collective navigation and long-distance migration. Now it is time to bring together the diverse field settings and skills, the various monitoring and analytical techniques, and the different collaborators to move our research into a novel and challenging direction.

## REFRENCES

**1** Rotics et al. 2016. *Journal of Animal Ecology* 85: 938–947; **2** Flack et al. 2018. *Science*. 360: 911–914; **3** Flack et al. 2016. *Science Advances* 2: e1500931; **4** Cheng et al. 2019. *Ecology and Evolution* 9, 8945–8952; **5** Weinzierl et al. 2016. *Ecology and Evolution* 6: 8706–8718; **6** Nagy et al. 2018. *Philosophical Transactions of the Royal Society* B 373: 20170011. **7** Scacco et al 2019. *Royal Society Open Science* 6: 181440; **8** Flack et al. 2020. *Journal of Experimental Biology* 223: jeb.219337.

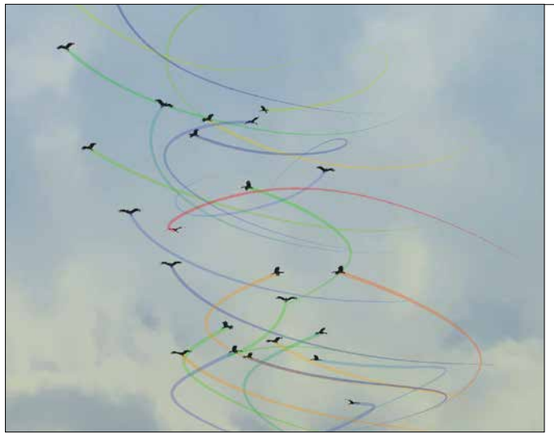


*Figure II.18 – Release/translocation experiment of juvenile white storks*

# Highlights

**May 2018**

Publication of "From local collective behavior to global migratory patterns in white storks" in *Science*

**April 2020**

Flack was awarded the James Heineman Research Award by the Minna-James-Heineman-Stiftung for outstanding young scientists working in the fields of biological and biomedical research.

**April 2021**

Acceptance of Flack's proposal for a DFG funded independent Emmy Noether research group examining the development of migratory behavior in white storks.

## Most important publications

34 — Pokrovsky I, Kölzsch A, Sherub S, Fiedler W, Glazov P, Kulikova O, Wikelski M, **Flack A.** 2021. Longer days enable higher diurnal activity for migratory birds. *Journal of Animal Ecology.*

*We show that long days allow birds to prolong their activity and increase their total daily activity, also highlighting that daylight availability may act as an ultimate cause of migration. [0 citations]*

13 — **Flack A,** Schaeffer PJ, Taylor JRE, Müller I, Wikelski M, Fiedler W. 2020. Daily energy expenditure in white storks is lower after fledging than in the nest. *Journal of Experimental Biology* 223: jeb219337.

*We examined long-term estimates of energy expenditure by looking at heart rate measurements as a qualitative proxy of energy expenditure rates. [1 citation]*

32 — **Cheng Y,** Fiedler W, Wikelski M, **Flack A.** 2019. "Closer-to-home" strategy benefits juvenile survival in a long-distance migratory bird. *Ecology and Evolution* 9: 8945–8952.

*The first autumn migration is the riskiest period for juvenile white storks but those that migrate shorter distances have lower mortality risks. [11 citations]*

273 — **Flack A*,** Nagy M*, Fiedler W, Couzin ID, Wikelski M., 2018. From local collective behavior to global migratory patterns in white storks. *Science* 360: 911–914.

*The exploration of leadership roles in the global migration of white storks: analysis of individual and group movements on multiple scales. [50 citations]*

* joint first co-authors

39 — Nagy M, Couzin ID, Fiedler W, Wikelski M, **Flack A.** 2018. Synchronization, coordination and collective sensing during thermalling flight of freely migrating white storks. *Philosophical Transactions of the Royal Society* B 373: 20170011.

*Using the motion of a flock of soaring storks, we examined the dynamic variation of airflow within thermal updrafts and determined the specific environmental conditions surrounding the flock. [18 citations]*

*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

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*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*





## Group Leader

# Andrea Flack

+ PhD: 2013, University of Oxford, with Dora Biro and Robin Freeman
+ Joined MPI: 2013 as postdoc
+ Group Leader since: 2020; non-tenured
+ Selected fellowships, grants & awards: DFG Emmy Noether Research Group (2021), James Heineman Research Award (2020), Fellowship of the Christiane Nüsslein-Volhard-Foundation (2017-2019)
+ Lifetime publication record: 27 publications, 503 citations, h-index: 11
+ Mean hours of teaching per week during semesters at U KN: 0

## Collective Migration Group

**3** Number of group members

**20** Number of peer-reviewed papers

**67%** Percentage international group members

**100%** Percentage female group members

**1** Number of finished Doctoral Students

**1 BSc & 0 MSc** Number of finished students

**380,000 €** Third-party funding granted (CASCB, International & German foundations)

# RESEARCH GROUP CAUSES, MECHANISMS AND CONSEQUENCES OF SONGBIRD MIGRATION

## GROUP LEADER: JESKO PARTECKE

What are the ultimate causes, mechanisms, benefits, and consequences of a migratory life? We study these fundamental questions using the common blackbird, which is either stationary year-round, partial, or fully migratory. We use ICARUS tracking and logger technology to determine natural movement behavior at unprecedented fine-scale temporal and spatial resolutions. In our common garden aviary facilities, we breed and experimentally manipulate the environmental conditions of individuals originating from year-round resident, partial, or full migrant populations. Using reciprocal translocations, we release captive-bred individuals back into each of the parent environments to study gene-by-environment interactions of movement decisions.

## Research achievements

Our past work has primarily focused on one partially migratory population in Germany, which contains both resident and migratory individuals (1-4). Using traditional radio tracking and geolocator techniques, we showed that non-breeding strategies (migrant/resident) in common blackbirds are highly consistent within individuals across years, indicating that these strategies may be intrinsically hard-wired. Moreover, these partially migratory birds conduct their migration flights similarly to obligate migrants: they migrate at night (4) and their timing of migration is seasonally fixed as well as highly repeatable within individuals across years. We also showed that migratory life has, despite the risks, survival benefits over residency during the non-breeding season (5). Building on these findings, Nils Linek (Doctoral Student) used implantable heart rate loggers to provide a novel perspective on the energetics of migrant and resident individual blackbirds of the same partial migrant population (6).

### BLACKBIRD BREEDING PROGRAM

During the last four years, we expanded our research program by including additional populations across the geographical range exhibiting year-round residency, partial, or full migration. Linek and other colleagues tested to what extent migrants of different populations rely upon the same range-wide cues or whether they use population-specific cues to time their migration. In addition, we developed a large-scale breeding program in which blackbirds originating from our field sites are bred under identical environmental conditions in our aviaries. This will allow us to study the ontogeny of movement decisions later in life and to breed F1 generations for reciprocal translocation experiments (Figure II.19).

### EARLY LIFE AND THERMOREGULATION

Developing young animals rely on parental care to buffer them from harsh conditions, and the decisions made by parents regarding when and where to reproduce affects the environment the offspring experiences. In our breeding aviaries, Ryan Shipley (Postdoc) performed manipulations of ambient nest temperatures to study the extent to which early-life conditions shape thermoregulatory capacity (i.e., the energetic costs and ability of birds to regulate their own body temperature with varying environmental temperatures) and ultimately the phenotypes that are linked to movement (migration, dispersal) and reproductive strategies later in life.

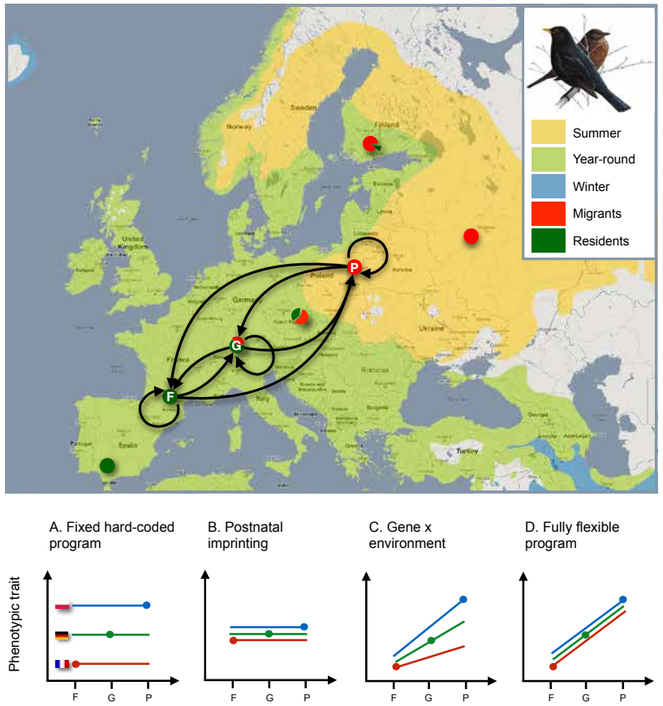


*Figure II.19. – Concept of reaction norm. Testable predictions of reciprocal-translocation experiments of aviary-bred and wild-caught juvenile and wild-caught adult blackbirds using the concept of reaction norms: (Scenario A): A fixed hard-coded migration program will be confirmed if translocated birds will exhibit their origin-specific phenotype at all sites. In contrast, (Scenario D) the fully flexible program will be supported if translocated birds adjust their migratory strategies to the origin-specific overwintering strategies. If (Scenario B) our aviary-bred birds will show "German strategies" at all release sites and wild-caught juveniles their origin-specific behavior, postnatal imprinting could be one (testable) key mechanism for generating migratory strategies. Finally, (Scenario C) the existence of gene x environment interactions can be quantified when birds of different origin on the one hand adjust their migratory strategies to the environmental conditions to which they are exposed to, but also show population-specific reaction norms in their response. Blue line depicts Polish, green line German, and red line French birds' reaction norms. Points on lines represent the location where birds originally came from. Release sites on the x-axis are France, Germany, and Poland.*

### FAT ACCUMULATION AND MIGRATION

Birds use fat to fuel migration and previous studies suggest that birds often accumulate massive amounts of certain fats prior to migration. Cornelia Twining (Postdoc) and Shipley fed common garden blackbirds from resident, partial, and fully migratory populations $^{13}$C-labelled fats to investigate whether variation in migratory strategies drives differences in the accumulation of physiologically important fats before and during autumn migration. We found that over the course of the autumn migration season, fully migratory Russian blackbirds consume more food, gain more weight, exhibit greater migratory restlessness, and preferentially accumulate more omega-3 fatty acids than other populations even though all individuals experience the same environmental conditions in our common garden aviary breeding program.

### DISPERSAL ECOLOGY AND EVOLUTION

Tamara Volkmer (Doctoral Student) studies the dispersal behavior of blackbirds expressing either resident or migratory lifestyle. For the first time, we can now study the first year of life, one of the most critical phases in their life history, allowing us to explore many significant, but unresolved questions about dispersal ecology and evolution, such as what are the costs and benefits of staying closer to the place of birth. Using both wild and aviary-bred immatures tagged with ICARUS GPS tags (Figure II.20), we aim to resolve the question of whether migrant and resident individuals differ in their dispersal strategies.

### GENOMIC BASIS OF MIGRATION

In contrast to other migratory model systems where migratory traits vary continuously, the beauty of our system is the clear-cut behavioral dichotomy of migrant versus resident phenotypes, which makes it a powerful model system to also study the genomic basis of migration. With colleagues at the U KN, we performed transcriptomic analyses and detected four differentially expressed genes between migrants and residents which may play crucial roles in determining the decision to migrate or control physiological processes required for migration (7). In a follow-up study with Miriam Liedvogel (MPI of Evolutionary Biology, Plön), we sequenced whole genomes of resident, partial, and full migrant blackbirds to search for genomic differences which may be related to resident and migrant phenotypes. Preliminary data indicate clear differences in allele frequencies at two distinct genomic regions of chromosome 1 and 3, between resident and migrant individuals.

# Future research agenda

Despite impressive progress in studying the ecology and evolution of migration, we are still far from understanding the rules of migratory life. One of the biggest gaps in our biological knowledge is simply understanding how individuals behave under natural conditions. In the next years, we will take full advantage of the concept of reaction norms using reciprocal translocation experiments, to study the (epi)-genetic and environmental effects on phenotypic expression (Figure II.19). We will answer questions such as what will happen if a Spanish or French year-round resident blackbird originating from our breeding program is translocated to Russia or Poland? Will these translocated birds be able to "switch on" the machinery, which is necessary for migration, but never expressed in those populations in their native environment? On the other hand, what will a Russian or Polish fully migratory blackbird decide to do if it is transported during the summer to wintering sites in Southern France or Spain? Will the translocated individuals be able to adjust their migratory program by shutting it down using current environmental information to which they are exposed to after translocation? With Katherine Snell (Postdoc), we will bring a macroecological approach building upon the field-derived heart rate data by Linek to test if the species-energy relationship persists in a dynamic environment characterized by flexible large-scale animal migration. We can now test environmental influences on behavioral traits by experimentally manipulating these traits, selecting for specific traits in captivity—aided by our increasing knowledge on genetic markers—and releasing these individuals into the wild to test their reaction norms in relation to changing environments. This setup allows us to finally test gene-by-environment interactions in essential life-history traits such as migration. While previously impossible to perform such studies, we are able to make significant progress in this research field to test our purported textbook knowledge under natural settings.

## REFRENCES

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*Figure II.20. -*
*Release of our aviary-bred immature blackbirds tagged with ICARUS GPS tags in collaboration with our young "MaxCine fellows".*

# Highlights

**2017-2021**

A long-term breeding program for common blackbirds is established for performing phenotypic experimentations.

**July 2019**

Development and testing of ICARUS GPS tags for use on small animals.

**2017–2021**

The successful release of 707 aviary-bred juveniles in the wild.

## Most important publications

**Linek N, Volkmer T, Shipley JR, Twining CW, Zúñiga D,** Wikelski M, **Partecke J.** 2021. A songbird adjusts its heart rate and body temperature in response to season and fluctuating daily conditions. *Philosophical Transactions of the Royal Society* B. 376: 20200213.

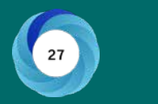
*Using implantable heart rate and temperature loggers, we show that the body temperature of free-ranging resident blackbirds decreased and heart rate increased with decreasing ambient temperature. These flexible adjustments are accompanied by an overall seasonal reduction in heart rate and body temperature. [1 citation]*


**Partecke J,** Hegyi G, Fitze PS, Gasparini J, Schwabl H. 2020. Maternal effects and urbanization: Variation of yolk androgens and immunoglobulin in city and forest blackbirds. *Ecology and Evolution* 10: 2213-2224.

*It has often been argued that the phenotypic responses to urban environments could be the result of micro-evolutionary changes. We show that hormone-mediated maternal effects may contribute to differences in behavioral and physiological traits between city and forest individuals. [2 citations]*

Schwabl H, **Partecke J.** 2020. Developmental programming of the adrenocortical stress response by yolk testosterone depends on sex and life history stage. *Journal of Experimental Biology* 223: jeb220152.

*Developmental exposure of embryos to maternal hormones such as testosterone in the avian egg influences the expression of multiple traits, with certain effects being sex-specific and lasting into adulthood. We report that baseline corticosterone levels and the stress secretion profile of corticosterone are modified by in ovo testosterone in a sex-specific and life history stage-dependent manner. [0 citations]*




Franchini P, Irisarri I, **Fudickar A, Schmidt A,** Meyer A, Wikelski M, **Partecke J.** 2017. Animal tracking meets migration genomics: transcriptomic analysis of a partially migratory bird species. *Molecular Ecology* 26: 3204-3216.

*We compared gene expression of radio-tracked resident and migrant individuals of the same partial migrant population using high-throughput transcriptomics. We detected four differentially expressed genes between migrants and residents which may play crucial roles in determining the decision to migrate, or in controlling the physiological processes required for the onset of migration. [21 citations]*


**Zúñiga D,** Gager Y, Kokko H, **Fudickar AM, Schmidt A,** Naef-Daenzer B, Wikelski M, **Partecke J.** 2017. Migration confers winter survival benefits in a partially migratory songbird. *eLife* 6: e28123.

*Using a combination of capture-mark-recapture and radio telemetry, we compared survival probabilities between migrants and residents. Our results support theoretical models that evolution of migration should confer survival benefits, and thus provide empirical evidence to understand the evolution and maintenance of migration. [14 citations]*


*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

*All publication and citation figures and metrics are based on Web of Sciences on May 31, 2021.*

*Dept./Group members in bold.*

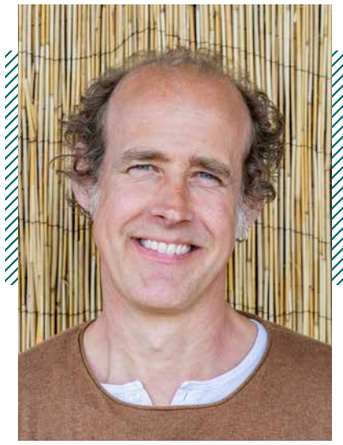
*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*



## Group Leader



# Jesko Partecke

+ PhD: 2002, University of Munich & Max Planck Institute Seewiesen, with Ebo Gwinner
+ Past positions: Postdoc, MPI Seewiesen (2003), Postdoc, Washington State University (2004-2006), Research Scientist, MPI Seewiesen (2006-2008)
+ Joined MPI: 2008 as Group Leader; tenured
+ Selected fellowships, grants & awards: Research Fellowship, Alexander von Humboldt Foundation (2004), VW Foundation Research Grant (2007)
+ Lifetime publication record: 36 publications, 2,162 citations, h-index: 24
+ Mean hours of teaching per week during semesters at U KN: 0

## Causes, Mechanisms and Consequences of Songbird Migration Group

**7**
Number of group members

**9**
Number of peer-reviewed papers

**57%**
Percentage international group members

**43%**
Percentage female group members

**1**
Number of finished Doctoral Students

**1 BSc & 0 MSc**
Number of finished students

**201,000 €**
Third-party funding granted (European Union, Alexander von Humboldt Foundation)

# RESEARCH GROUP ANIMAL-ENVIRONMENT INTERACTIONS

## GROUP LEADER: KAMRAN SAFI

The Animal-Environment Interactions Group uses computational methods to investigate the relationship between animals and the environment at all biological scales from individuals to species communities. From the causes and consequences of individual movement to the distribution of biological diversity globally or the eco-evolutionary forces that have shaped species traits deep in evolutionary time, we investigate how the biological domain is defined and shaped by the environment and its dynamics. Based on the understanding of these interactions we predict changes in animal behavior, population sizes, or biodiversity, and we aim to sense changes in environmental conditions through animals.

## Research achievements

In the past years, we have set our research emphasis on two major areas of research. First, the development of an adequate methodology to, second, investigate environmental interactions of animals across scales. Through the rapid technological developments in bio-logging devices, as well as the accessibility of an ever-increasing volume of remote sensing and aerial imagery, classic methodologies of ecological analysis have become inadequate. As a research community in the bio-logging domain, we are challenged by big data issues where the density and volume of the data produced in conjunction with the new sensors deployed pose significant challenges in data storage and analysis. Our research on animal-environment interactions in the various projects necessitates that we actively engage in developing new methods. Consequently, we have developed a series of new methodological approaches (1–8) with an emphasis on publishing all innovations openly as well as making algorithms easily available.

### ENERGY LANDSCAPES

Based on the analysis of remote sensing data and weather information fused with high-resolution biologging information, Martina Scacco (Doctoral Student) and Elham Nourani (Postdoc) investigated the energy landscape that facilitates efficient soaring flight in birds over land and water. The distribution of the energy in the landscape is a fundamental force in avian flight and affects their decisions in route choice and space use (9). Scacco focused on the interactions of uplift over terrestrial landscapes, showing that static land use information can reliably inform about the presence of thermal uplift as indicated by the behavior of the birds as well as through their energy use measured by acceleration sensors (10; Figure II.21). Nourani established the concept of energy seascapes showing that under certain circumstances uplift can exist at sea, against prevailing opinion, affecting the route choice of migrating terrestrial raptors when crossing the sea (11, 12). The distribution of atmospheric energy is an important factor in the movement of all flying animals and our studies show new ways of quantifying the causes and consequences of the dynamic aerial flows (13-16). Teja Curk (Doctoral Student) investigated the factors affecting the timing and route choice of

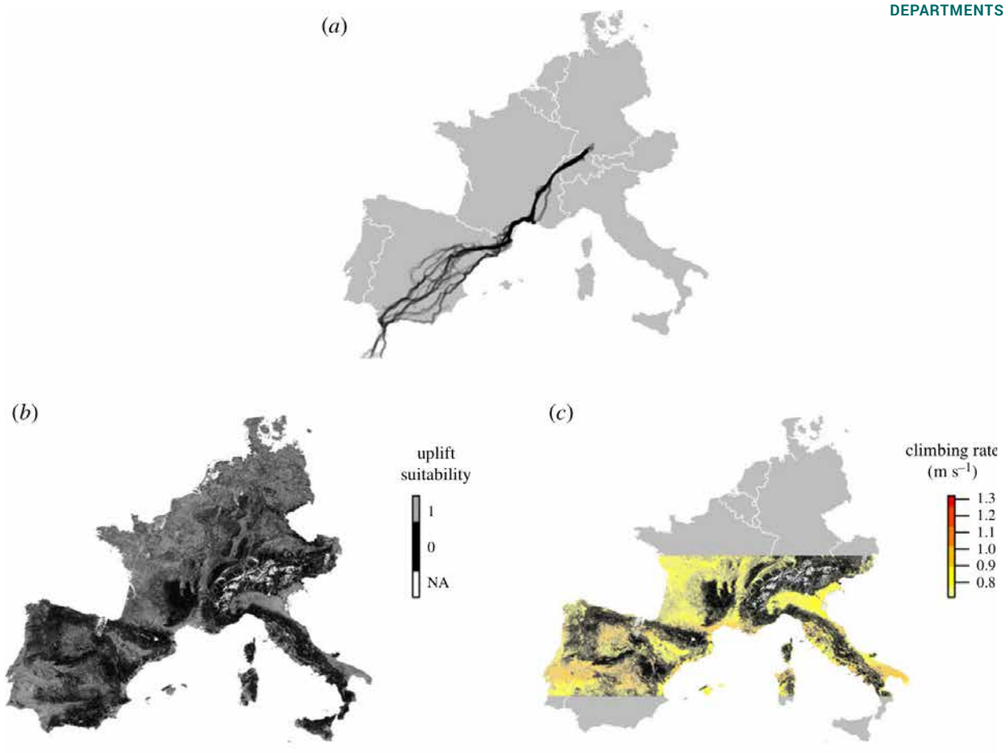



*Figure II.21 –*
*Based on the fine scale behavior of white storks carrying biologging devices (a) we predicted the occurrence of thermal uplift (10) based on static landscape layers (b) and estimated the strength of the thermal uplifts predicted (c). While it was possible to predict the occurrence of thermals based on landscape features, predicting their strength required the addition of atmospheric information such as wind direction and strength. The modeled energy landscape explained the overall differences in energy expenditure also measured by the biologging devices along the migratory journey of the animals and therefore can provide relevant information about how changes in the landscape composition could affect choices in and the cost of migration.*

an arctic raptor community, focusing on the landscape as well as wind conditions, with a spotlight on how dietary specialization influences movement patterns and migratory strategies (17). We can show that dietary specialization correlates with movement patterns that the different species express, placing them on a gradient from regular migrant to nomadic species and defines how well they can cope with the receding snowmelt in the arctic environment. This suggests that environmental productivity should show its traces in the way different species move in relation to seasonal changes.

### BRIDGING MOVEMENT & OCCURRENCE

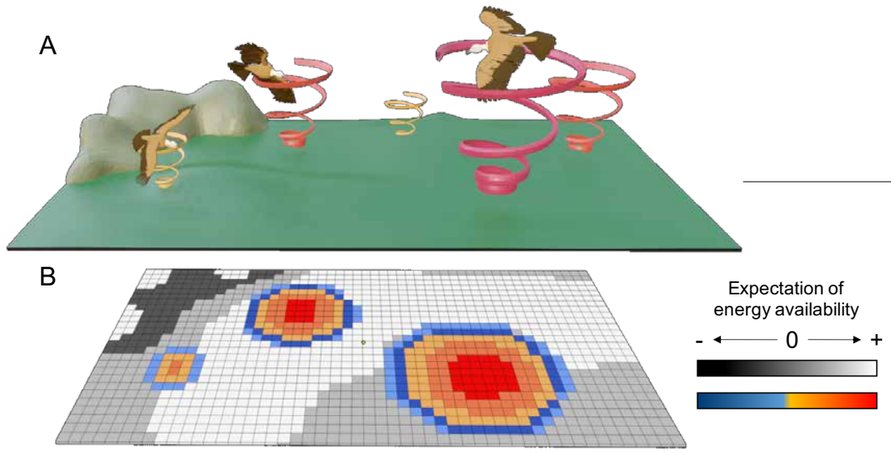
Based on our understanding of the relationships between animals and their environments, we have also researched the large-scale spatial distribution of species and the consequences of global change on species communities. Based on occurrence data and remote sensing time series information, Alaaeldin Soultan (Doctoral Student), as well as Hosein Yusefi (external Doctoral Student), investigated the resilience of species communities of the warm dry ecosystems in the Sahara and Middle East (18-22). All of our studies indicate that these ecosystems represent highly specialized assemblages of species with limited capacity to deal with global change and are thus at particular risk of extinction. Modeling species communities based on occurrence data as well as modeling animal environment interactions based on movement data are conceptually very similar, yet the methodologies differ. However, fundamentally the presence of species in space should be a consequence of their movements and there should be a clear interdependence between the different scales of environmental interactions. We have investigated ways of integrating data across scales to merge movement data with occurrence data to better understand connectivity based on empirical distribution information and known movement processes. This work has been used by Marielle van Toor (Doctoral Student), for example, to successfully model connectivity of waterfowl populations explaining the similarity and potential spreading pathways of avian influenza (7).

# Future research agenda

The Animal-Environment Interaction Group will continue on the successful path of the past years with an emphasis on methodology and interactions across scales. The Group has taken two routes to tackle the technological challenges: along with our research on animal-environment interactions in the various projects, we include the development of new methodological approaches with peer reviewing and publishing our innovations as well as making algorithms available as part of our mission. We have established and continue to maintain and create R-libraries to disseminate our efforts in this area to the wider research community. We also plan to continue to increase the cadence in innovation and participation by the development of moveApps—a toolbox aimed at the analysis of animal movement. Through moveApps we aim to extend the citizen science approach to the implementation and development of analytical applications in an environment that allows anyone to contribute and engage in the analysis of movement data. With moveApps, we aim to bring together movement ecologists in possession of data and in need of analytical tools with people who have skills in programming and the interest in providing time to extend the platform's capabilities. Thus we increase the sheer number of people being able to contribute and also bring supply and demand closer together.

On the animal-environment interactions route, the Group will focus on exploiting the high-resolution data gained from Inertial Measurement Units (IMUs) to learn about the very fine scales of interactions with the environment. In particular, the use of the energy landscape in large birds of prey is of particular interest. This includes the social aspects that sensing in such a complex and dynamic environment necessitates. Here, Hannah Williams (Postdoc) has proposed a novel concept of optimal movement theory (23; Figure II.22), which we would develop through field experiments and theoretical models.

In the past years, we have also established a field project in the European Alps on juvenile golden eagles to investigate dispersal and ontogeny of soaring flight abilities. We are currently analyzing the data that we have collected so far in order to investigate the juvenile dispersal and factors that affect survival in a saturated population, as well as the ontogeny of soaring flight in a highly dynamic and complex energy landscape. In the future, we would like to investigate how precisely the atmospheric landscape affects the distribution of species and the evolution of the sensory systems including its effects on the social organization of large raptors. From this understanding, we aim to predict the changes in energy expenditure and thus the occurrence of these species and the ecosystem services they provide in the future years under global change.



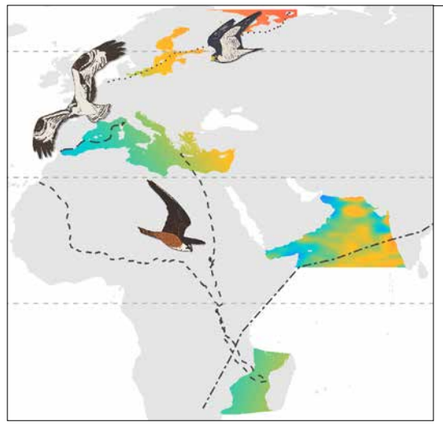



*Figure II.22 -*
*The concept of "Optimal Movement Theory" reconciles the multitude of decision landscapes that the field of movement ecology has identified as important when modeling animal movement, thereby introducing the entities such as certainty, memory, and social information in integrating these layers of decision landscape in a holistic framework (23).*

## REFERENCES

**1** Fleming et al. 2021. *bioRxiv*; **2** Remelgado et al. 2020. Remote Sensing in *Ecology and Conservation* 6: 93-104; **3** Schwalb-Willmann et al. 2020. *Methods in Ecology and Evolution* 11: 664-669; **4** Péron et al. 2020. *Animal Biotelemetry* 8: 5; **5** Aspillaga et al. 2019. Methods in *Ecology and Evolution* 10: 1551-1557; **6** Kranstauber et al. 2017. Methods in *Ecology and Evolution* 8: 155-160; **7** van Toor et al. 2018. *Landscape Ecology* 33: 879–893; **8** Remelgado et al. 2019. Methods in *Ecology and Evolution* 10: 1212-1221; **9** Kranstauber et al. 2015. *Ecology Letters* 18: 1338-1345; **10** Scacco et al. 2019. *Royal Society Open Science* 5: 181440; **11** Nourani et al. 2018. *Royal Society Open Science* 5: 171555; **12** Nourani et al. 2020. *Biology Letters* 16: 20190797; **13** O'Mara et al. 2021. *Current Biology* 31: 1311-1316; **14** McCracken et al. 2016. *Royal Society Open Science* 3: 160398; **15** Péron et al. 2017. *Journal of Applied Ecology* 54: 1895-1906; **16** O'Mara et al. 2019. Frontiers in *Ecology and Evolution* 7: 200; **17** Curk et al. 2020. *Scientific Reports* 10: 7220; **18** Soultan et al. 2019. *Scientific Reports* 9: 955; **19** Soultan, Safi. 2017. *PLoS ONE*. 12: e0187906; **20** Soultan et al. 2020. *Ecology and Evolution* 10: 8669-8680; **21** Yusefi et al. 2021. *Diversity and Distributions*; **22** Yusefi, et al. 2019. *Journal of Biogeography* 46: 2433-2443; **23** Williams, Safi. 2021. Trends in *Ecology and Evolution.*

# Highlights

## 2017-2019

Contributing to the open and communicative culture of the MPI-AB. Group members have fostered many inter-Group research collaborations, and dedicated time to positions including Doctoral/Postdoc representatives and Chair of the Works Council.

## January 2019

Our research uncovering the energy landscape and how this differs between species defining ecological niche space. The cost of movement has largely been neglected in how the suitability of the environment permits co-existence.

## February 2021

Development of moveApps—a toolbox for the analysis of animal movement. By allowing more researchers to work in close contact with developers of applications, the project has the potential to have a fundamental impact on research.

## Most important publications

| | | |
|---|---|---|
| 22 | **Nourani E,** Vansteelant WMG, ByholmP, **Safi K.** 2020. Dynamics of the energy seascape can explain intra-specific variations in sea-crossing behaviour of soaring birds. *Biology Letters* 16: 20190797. | *The concept of energy fueling birds' movement was taken to the sea to show that there is an energetic subsidy at sea through uplift that birds might be using, which explains the different timing in migration between juveniles and adults in the same soaring bird species. [4 citations]* |
| 1538 | Rutz C, **Loretto MC,** Bates AE, Davidson SC, Duarte CM, Jetz W, Johnson M, Kato A, Kays R, Mueller T, Primack RB, Ropert-Coudert Y, Tucker M, Wikelski M, Cagnacci F. 2020. COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. *Nature Ecology and Evolution* 4: 1156–1159. | *This publication exemplifies the collaborative nature of our work, the innovative aspect of investigating animal-environment interactions, and how natural experiments provide unique opportunities to study them in the wild. [75 citations]* |
| 35 | **Soultan A,** Wikelski M, **Safi K.** 2019. Risk of biodiversity collapse under climate change in the Afro-Arabian region. *Scientific Reports* 9: 2045-2322. | *This paper operates at the level of species communities and uses animal-environment interactions to predict the direct future of the species communities in dry areas. [8 citations]* |
| 22 | **Scacco M,** Flack A, Duriez O, Wikelski M, **Safi K.** 2019. Static landscape features predict uplift locations for soaring birds across Europe. *Royal Society Open Science* 6:1-7. | *This paper takes a new view of the energy landscape and shows that it is possible to use animal behavior to predict environmental conditions to a physiologically relevant degree. [10 citations]* |
| 29 | **van Toor ML, Kranstauber B,** Newman SH, Posser D, Takekawa JY, Technitis G, Weibel R, Wikelski M, **Safi K.** 2018. Integrating animal movement with habitat suitability for estimating dynamic migratory connectivity. *Landscape Ecology* 33: 879–893. | *This publication bridges individuals to whole species distributions using animal movement and environmental information. It exemplifies our cross-scale ambitions for understanding the basis and predicting the consequences of animal-environment interactions. [5 citations]* |

277 *Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

*All publication and citation figures and metrics are based on Web of Sciences on May 31, 2021.*

*Dept./Group members in bold.*

*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

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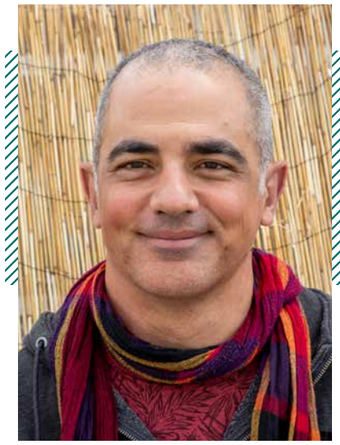
## Group Leader

# Kamran Safi



+ PhD: 2007, University of Zurich, with Gerald Kerth and Barbara König
+ Past positions: Postdoc, Zoological Society of London (2007-2009)
+ Joined MPI: 2009 as Group Leader; tenured
+ Lifetime publication record: 77 publications, 3,393 citations, h-index: 30
+ Mean hours of teaching per week during semesters at U KN: 2

## Animal-Environment Interactions Group

**11** Number of group members

**64** Number of peer-reviewed papers

**82%** Percentage international group members

**73%** Percentage female group members

**2** Number of finished Doctoral Students

**0 BSc & 1 MSc** Number of finished students

**343,000 €** Third-party funding granted (Top 3 sources: European Union, International Foundation, DAAD)

# MAX PLANCK RESEARCH GROUP COGNITIVE AND CULTURAL ECOLOGY

# MAX PLANCK RESEARCH GROUP COGNITIVE AND CULTURAL ECOLOGY

## GROUP LEADER: LUCY APLIN

Traditional views of Darwinian evolution focus on selection on genetic variation as a means of adaptation. However, this neglects potential contributions from the over-generational transmission of knowledge. In the Cognitive and Cultural Ecology Group, we study these processes, adding to emerging evidence that culture in animals can drive cognitive evolution, be locally adaptive, and enable behavioral flexibility in changing environments. We have two main lines of research: controlled experiments investigating cultural evolutionary dynamics in parids or parakeets, and wild fieldwork on the socio-cognitive ecology of urban parrots. We use state-of-the-art approaches from citizen science to automated tracking, from detailed observations to large-scale experiments.

# Research achievements

### CULTURAL EVOLUTION AND INHERITANCE IN PARIDS

In previous work published in *Nature* (1), we showed that wild songbirds could transmit new foraging techniques through social networks to form population-specific traditions. Using this same paradigm, follow-up research in *PNAS* (2) revealed that traditions can exhibit cultural evolution to environmental change (change in cultural traits in response to 'Darwinian-like' processes; (3)). Extending this work, Sonja Wild (Postdoc) and Michael Chimento (Doctoral Student) tested whether recombination across cultural lineages could lead to increasing complexity (3), finding that while multi-step cultures arose, they were underpinned by social learning of simpler components (4). Most recently, Chimento undertook a large-scale captive experiment with detailed behavioral tracking to reveal that cultural selection can drive increasing efficiency even in the absence of external selection pressures (5). Similar to previous work, we found a critical role for demography, with cultural evolutionary rates determined by population turnover. This work was published in *Current Biology* (5) and was the focus of a dispatch in the same journal (6).

Most of our previous work has focused on the spread of innovation between adults in one generation (7). To investigate the ontogeny of social learning, Wild is currently conducting a series of experiments in wild parids using "selective foraging puzzles", which have multiple solutions that can be locked depending on the ID of the visiting bird (Figure II.23). We are using this paradigm to understand: (i) the role of transmission modes (e.g., parents vs. peers) in shaping learned foraging behavior, and (ii) how individuals vary across development.

### COGNITIVE ECOLOGY IN PARROTS

Our recent work has expanded to include a focus on the evolutionary ecology of cognition in parrots. Psittaformes are famous for evolution of intelligence, as well as for extreme longevity. In collaboration with Species 360, Simeon Smeele (Doctoral Student), and Mary Brooke McElreath (Co-supervisor), we used data on >133,800 parrots from zoo collections in a comparative analysis, finding that brain size is the best predictor of longevity, consistent with the Cognitive Buffer Hypothesis (Smeele et al. in prep). We are now expanding this work to examine life history factors predicting cognitive evolution, including those linked to sociality (8, 9). Nowhere is the influence of cognition on ecology more pronounced than under anthropogenic change (10). To study this, we established a new system on sulphur-crested cockatoos in Sydney, Australia. Parrots can be challenging to study in the wild, and as a consequence their cognitive ecology is understudied. Over the last 3 years, Julia Penndorf (Doctoral Student) and Barbara Klump (Postdoc) have developed methods to overcome these challenges. First, similarly to other studies, we found that parrots are extremely difficult to re-trap. In response, we have moved to non-invasive techniques inspired from primatology (11). We habituate birds to people/locations, mark individuals with paint combinations, pluck feathers for genetic analysis, weigh individuals on scales, and census roost membership. In this way, we mark almost 100% of individuals in a given site, take detailed observations, and conduct behavioral experiments. Paint marks are temporary (~3mths), genetic samples can be back-referenced, following individuals over years. Second, we make broader observations using the "many eyes" of citizen science, e.g., developing the popular "BigCityBirds app" (12) to gather reports of occurrence and behavior. (Figure II.23; 12).

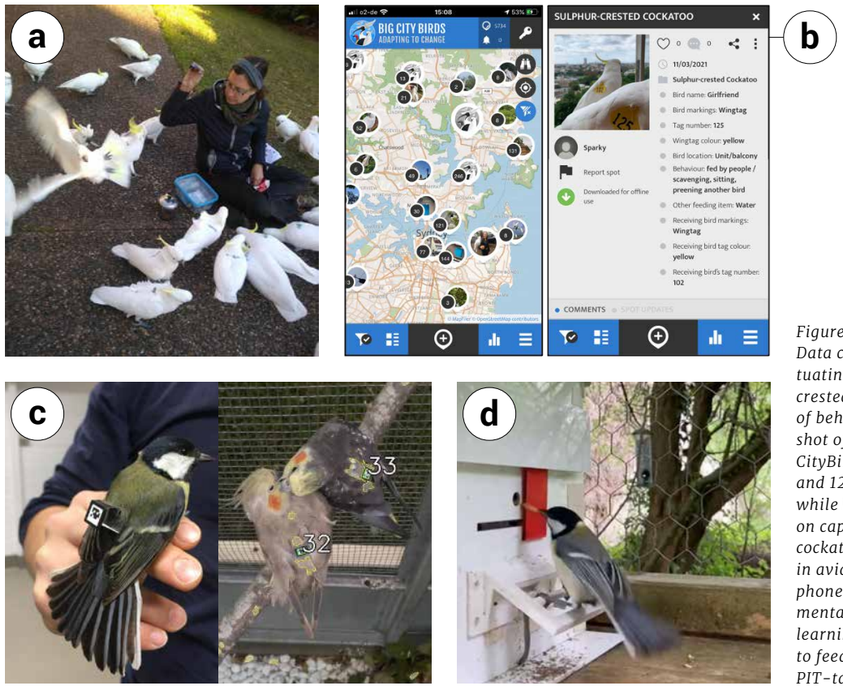



*Figure II.23. – Data collection techniques. (a) Habituating and paint marking wild sulfur-crested cockatoos for later observations of behavior. (b) Citizen science; screenshot of map and example report on BigCityBirds. Here wing-tagged birds 102 and 125 were observed allopreening while being provisioned. (c) Barcodes on captive great tits (wild-caught) and cockatiels, allowing behavioral tracking in aviaries. Cockatiels also wear microphones for vocal tracking. (d) Experimental "puzzle-box" for studying social learning in wild great tits, with door to feeder unlocked after detection of PIT-tag (visible on left leg).*

In our last field season (2019), we intensively followed >500 individuals, and gained new insights into social cognition. For example, we showed that despite a highly fluid social-system where individuals may interact with hundreds of individuals (from their roost and neighboring roosts), there is evidence for linear dominance hierarchies and social discrimination. Individuals maintain long-term associations (12), preferentially associate with kin (Penndorf et al. in prep), and strategically interactions based on knowledge of hierarchies (Penndorf et al. in prep).

### CULTURAL ECOLOGY IN URBAN-ADAPTED PARROTS

With collaborators, we recently published a paper in *Science* arguing that animal cultures can have implications for conservation (13, 14). Yet depending on learning dynamics, culture might also be a source of behavioral flexibility. In one such example, Klump used observations at three levels (landscape, between-area, individual/within-area) to describe geographic spread and diversification into local subcultures of a new urban-adapted foraging behavior in sulphur-crested cockatoos: "lifting bin-lids" (Figure II.24). This work has just been published in *Science* (15). We are now tracking the emergent behavioral arms race between humans and cockatoos, as people protect bins from attack while birds learn to defeat these measures (Klump et al. in prep).

# Future research agenda

Parrots are equally famous for their vocal flexibility (16), with evidence for local dialects and individual and group-level signatures (17). Partly because of this extreme vocal flexibility, classifying parrot vocalizations has been an analytical challenge. Work from our Group and others, including at the MPI-AB, has recently begun to find methodological solutions to these challenges. We, therefore, plan to use this opportunity to include a vocal perspective in our future work. For example, Smeele is planning to extend his comparative analyses to examine potential correlates between vocal and social complexity in Psittaformes, combining his current dataset with calls scraped from online sources.

In an experiment just started, Stephen Tyndel (Doctoral Student) is exploring social dynamics of vocal convergence in replicated flocks of the smallest cockatoo species, the cockatiel. Individuals wear barcodes and microphones for detailed long-term tracking over two months. Birds were initially grouped with strangers and we are now tracking the concurrent development of social relationships and group-level social calls over time. This allows us to explore how group-level signatures emerge and shift revealing their function in fission-fusion societies.

Our current fieldwork on wild cockatoos is unfortunately disrupted by COVID-19. We have responded by extending our citizen science networks through the "BigCityBirds app", e.g., collecting reports of behavioral innovations across Sydney. Klump is doing pilot work to see if we can successfully conduct experiments on the balconies of citizen scientists across Sydney, e.g., to test whether birds in different locations show variation in food recognition or processing (indicative of local foraging cultures). In the future, we aim to combine this "novel census technique" with remote-sensing, movement tracking, and cultural-diffusion experiments, in order to undertake a landscape-level analysis of socio-cognitive responses to human impact.

## REFRENCES

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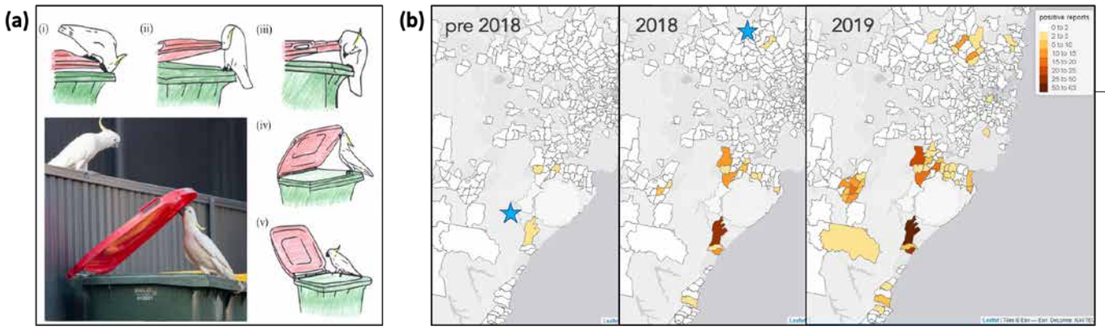


*Figure II.24. -*
*Bin-opening behavior in sulphur-crested cockatoos. (a) The behavioral sequence of bin opening, showing the 4-5 steps required for successful opening. Spatial variation in sequence components evidence emergence of local sub-cultures. (b) Map showing spatial spread of innovation. Suburbs with reports are white (negative) or colored (positive). Light grey areas are forest, medium grey are suburbs without reports, dark grey is water. Blue stars are likely sites of independent innovation, as indicated in diffusion analysis.*

# Highlights

## January 2018

Starting the Cognitive and Cultural Ecology Group. From n=1 in Jan 2018, the Group now comprises eight people, supported by the MPRGL Fellowship and external funding.

## July 2018

Establishing a study system on urban cockatoos and developing novel methods for wild parrots, including habituation, non-invasive marking/ genetic-tagging, and citizen science. Recent outputs include (15).

## January 2019 – April 2021

Establishing a lab system and captive experimental paradigm for parids and parakeets, recently resulting in the publication of our first major cultural evolution experiment (5).

## Most important publications

| | | |
|---|---|---|
| | **Klump BC**, Martin JM, **Wild S, Hoersch J**, Major RE, **Aplin LM**. accepted. Innovation and geographic spread of a complex foraging culture in an urban parrot. *Science.* | *Second paper from our work on cockatoos. We used observations at 3-levels (landscape, between-area, individual/within-area) to describe geographic spread and diversification into local subcultures of a new urban-adapted foraging behaviour, "lifting bin-lids". [0 citations]* |
| 257 | **Chimento MC, Alarcon-Nieto G, Aplin LM**. 2021. Population turnover facilitates cultural selection for efficiency in birds. *Current Biology* 31: 2477-2483. | *This was the first publication from my second Doctoral Student, who started in late 2018. It represents the cumulation of a large-scale experiment examining cultural evolution in birds. [1 citation]* |
| 35 | Cantor M*, **Chimento MC***, **Smeele SQ***, He P, Papageorgiou D, **Aplin LM****, Farine DR**. 2021. Social network architecture and tempo of cumulative cultural evolution. *Proceedings of the Royal Society* B 288: 20203107. | *This paper was a collaborative work between the Aplin Group and the Farine lab, and is of inter-disciplinary interest. We used theoretical modelling to elucidate the importance of social networks for cumulative cultural evolutionary dynamics. [1 citation]* |
| 28 | **Penndorf J, Aplin LM.** 2020. Environmental and life history factors, but not age, influence social learning about food: a meta-analysis. *Animal Behaviour* 167: 161-176. | *This paper represented many firsts – it was the first publication from my first Doctoral Student, Julia Penndorf, who started in Feb 2018. It was also my first senior author paper. [1 citation]* |
| 126 | **Aplin LM**, Major R, Davis A, Martin JA. 2020. A citizen science approach reveals long-term social network structure in an urban parrot, *Cacatua galertia. Journal of Animal Ecology* 90: 222-232. | *This paper uses novel methodological approaches to give first insights into social networks in wild parrots. It was the first paper resulting from my newly established study system. [2 citations]* |

*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

*All publication and citation figures and metrics are based on Web of Sciences on May 31, 2021.*

*Dept./Group members in bold.*

*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*



## Max Planck Research Group Leader

# Lucy Aplin

+ PhD: 2014, Australian National University
+ Past positions: Postdoc, University of Oxford (2014-2017)
+ Joined MPI: 2018 as Max Planck Research Group Leader; non-tenured
+ Selected fellowships, grants & awards: Junior Research Fellowship, St John's College, University of Oxford (2015), Max Planck Research Group Leader (2018), National Geographic Exploration Grant (2018), National Geographic Explorer (2019)
+ Lifetime publication record: 36 publications, 1,545 citations, h-index: 18
+ Mean hours of teaching per week during semesters at U KN: 3

## Cognitive and Cultural Ecology Group

**8**
Number of group members

**23**
Number of peer-reviewed papers

**75%**
Percentage international group members

**50%**
Percentage female group members

**0**
Number of finished Doctoral Students

**1 BSc & 1 MSc**
Number of finished students

**197,000 €**
Third-party funding granted (Top 3 sources: CASCB, National Geographic Society, DAAD)

# MAX PLANCK RESEARCH GROUP GENES AND BEHAVIOR

# MAX PLANCK RESEARCH GROUP GENES AND BEHAVIOR

## GROUP LEADER: SERENA DING

Nematodes are the most abundant animals on the planet (1), and they exhibit many collective behaviors including aggregation (2, 3), swarming (4, 5), towering (6, 7), and network formation (8). These behaviors are not only visually striking but also likely purposeful, and we want to understand the mechanism and function of these collective behaviors in the context of ecology and evolution. Our current work focuses on two *C. elegans* strains with solitary vs. hyper-social aggregation phenotypes. In the future, we will use wild isolates of various *Caenorhabditis* species to link natural genetic variation to behavioral variations at both the individual and the group level.

## Research achievements

During the past four years, our research has primarily focused on the differential aggregation and swarming behaviors between two *C. elegans* strains: the solitary N2 lab reference strain and the hyper-social *npr-1* mutant strain. Aggregation and swarming are related behaviors ubiquitous across all subclasses of the phylum Nematoda (9). In *C. elegans*, the genetic (2) and neuronal (10) basis of the contrasting behavior between N2 and the *npr-1* mutant worms was determined in the previous two decades. However, the behavior mechanism was lacking until we filled in this knowledge gap in 2019.

### INTERACTION RULES FOR SELF ORGANIZATION

We identified a set of three interaction rules that individual worms follow to self-organize and give rise to the solitary vs. tightly aggregating group level phenotypes (4). Using two-color simultaneous fluorescence imaging and automated multi-worm tracking, we obtained trajectories and postures that allowed us to precisely quantify many aspects of the behavior. We developed an agent-based mathematical model to link individual behavior to group-level phenotypes, by finding three key interaction rules: worms switch between high and low-speed states, they reverse upon leaving a cluster, and they perform taxis towards close neighbors. All three rules depend on neighbor density, and the interaction range is local. This finding confirms *C. elegans* aggregation as a bona fide collective behavior and provides valuable insights into a collective system at the mesoscopic scale that is much less studied than at the microscopic (e.g. cellular and active matter systems) and the macroscopic (e.g. animal herds) scale.

### AGGREGATION AND SWARMING

Our 2019 study also concluded that aggregation and swarming in *C. elegans* are related behaviors that employ the same underlying behavioral mechanisms.

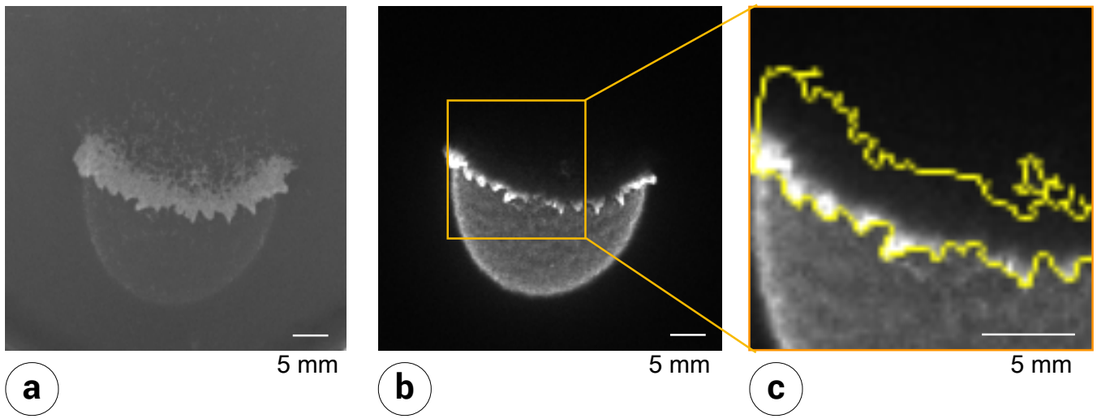


*Figure II.25. – Large-scale swarming of* npr-1 *mutant worms. A) Brightfield and B) bioluminescent images of a swarming front (white band in A), which is a traveling wave with protruding fingers on the leading edge (bottom of the band). The swarm sweeps over a bacterial food patch (white in B) from the top right to the bottom left direction. The boxed area in B is enlarged in C) with the outline of the swarm traced in yellow, to show that only the leading edge of the swarm is in contact with food and there is a higher concentration of bacteria at the front. Figure is taken directly out of (5).*

When we scaled up our aggregation model with more agents and extended the model with food depletion, we captured the emergence of collective swarming over a food patch that we observe experimentally (4). We also demonstrated that only the leading edge of the swarm is in contact with bacterial food and that the moving front leaves no trace of food behind as it sweeps past (Figure II.25)—results that hint at potential hygienic and energetic functions of collective swarming and warrant further exploration. We were only able to make these observations thanks to our new bioluminescence bacteria labeling method that detects only metabolically active bacteria (5). Previous fluorescence-based labeling methods detect residual fluorescence molecules in dead bacteria and have a much higher background, thus obscuring important observations such as ours.

### COLLECTIVE FORAGING

As we delved deeper into the functional aspects of collective behavior, we also explored whether collective foraging is advantageous in patchy food distribution environments in the absence of long-range communications. We developed an on-lattice model to show a theoretical advantage of collective foraging due to group formation alone when food is patchy, whereby social agents feed faster and more efficiently than solitary agents (11).

## Future research agenda

While studying the difference between N2 and *npr-1* aggregation has provided a prime example of how we can link genes, neuronal circuits, individual behavior, and collective behavior within one experimental system, the underlying *npr-1* mutation is a product of laboratory domestication (13) and does not exist in nature. We now have a collection of hundreds of sequenced *C. elegans* strains isolated from natural environments all over the world (14) showing no natural variation in the *npr-1* locus. However, most of these wild isolates aggregate to some extent with variations in their aggregation phenotype (Figure II.26). This provides an excellent opportunity to link genetic variation to behavioral variation in order to identify novel genetic drivers of collective behavior that may be evolutionarily relevant.

To do this, we need to screen through many worm strains to sample genetic diversity. We will use a new worm imaging system that we helped to develop to enable hundreds of simultaneous behavioral experiments (12). Each modular worm tracking unit uses an array of six cameras with a partially overlapping

field of view to cover all wells of a standard multi-well plate and can record at temporal and spatial resolutions that are sufficient for accurate worm tracking and postural estimation. We will extract high-dimensional behavioral features from the imaging data, and identify behavior-modifying genetic variants using genome-wide association study (GWAS) and mapping techniques. We will examine whether the genes are under selection and identify potential selective pressure from ecological data. We will also include hundreds of sequenced and georeferenced *C. briggsae* and *C. tropicalis* strains in our screening to provide the phylogenetic context for our analysis. We will collaborate with Erik Andersen (Northwestern University) for the mapping and Kay Hogins (Monash University) for the comparative genomics part of our work.

Another direction of our future research is to test how changing group composition affects the interactions and the collective phenomenon. We have preliminary data showing that the *npr-1* mutants and the Hawaiian wild isolate CB4856 can mix and form aggregates together. The behavioral variations we learn from the work above will provide the raw material for designing heterogeneous mixtures of worm groups, and we will integrate theoretical and experimental approaches to this end.

Last but not least, we will venture beyond aggregation and study high-density swarming and collective nictation. The swarming of tens of thousands of individuals forms a traveling wave with protruding fingers on the leading edge (Figure II.25). We will model this striking phenomenon and test the potential hygiene function of swarming using pathogenic bacterial food. As for collective nictation, we will develop imaging and tracking techniques for this 3D behavior to gain novel insights into individual interactions within a waving worm tower.

## REFRENCES

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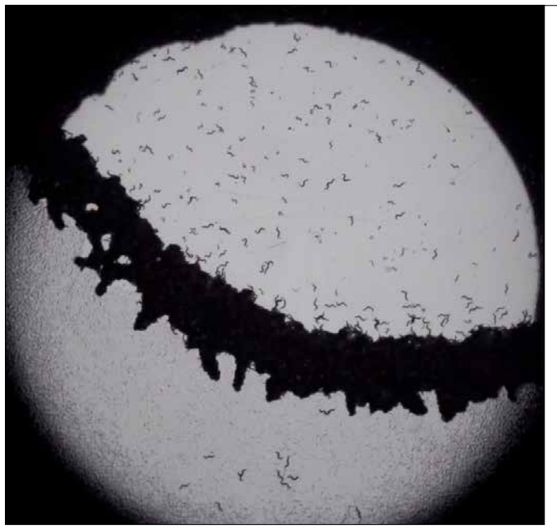


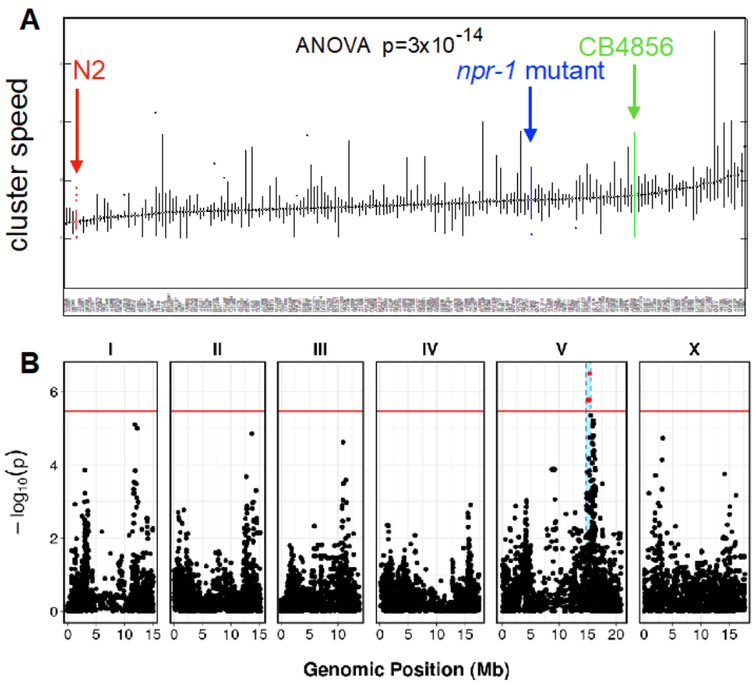



*Figure II.26. – Sample quantitative trait mapping. A) Preliminary screening of 198* C. elegans *strains shows natural variation in cluster speed during aggregation. Other than N2 (red) and the* npr-1 *mutant (blue), all other strains are wild isolates, including the CB4856 Hawaiian strain (green). B) GWAS mapping of this speed cluster feature reveals a quantitative trait locus on Chromosome V.*

# Highlights

### April 2019

Publication in *eLife*, linking individual behavior to group behavior in *C. elegans* by identifying a set of three interaction rules that underlie differential aggregation and swarming phenotypes (4).

### September 2020

Grant was awarded to Ding to start the Max Planck Research Group, Genes and Behavior, at the MPI-AB.

### April 2021

Helped to develop a state-of-the-art worm tracker system to enable a new class of behavioral experiments using high-throughput, high-content imaging (12).

## Most important publications

| | | |
|---|---|---|
| | Barlow I, Feriani L, Minga E, McDermott-Rouse A, O'Brien T, Liu Z, Hofbauer M, Stowers JR, Andersen EC, **Ding SS,** Brown AEX. 2021. Megapixel camera arrays for high-resolution animal tracking in multiwell plates. *bioRxiv* 10.1101/2021.04.16.440222. | *This paper describes a state-of-the-art worm tracker that can simultaneously image all wells of a standard multiwell plate at temporal and spatial resolutions needed for accurate automated worm tracking. [0 citations]* |
| 36 | **Ding SS,** Romenskyy M, Sarkisyan KS, Brown AEX. 2020. Measuring Caenorhabditis elegans spatial foraging and food intake using bioluminescent bacteria. *Genetics* 214: 577-587. | *This paper describes a novel method for simultaneous measurement of foraging in space and food consumption that is nearly 100-fold more sensitive than previously described methods. [4 citations]* |
| 8 | **Ding SS,** Muhle LS, Brown AEX, Schumacher LJ, Endres RG. 2020. Comparison of solitary and collective foraging strategies of Caenorhabditis elegans in patchy food distributions. *Philosophical Transactions of the Royal Society* B 375: 0382. | *This paper demonstrates the theoretical advantage of collective foraging owing to group formation alone in the absence of long-range interactions. [1 citation]* |
| 38 | **Ding SS,** Schumacher LJ, Javer AE, Endres RG, Brown AEX. 2019. Shared behavioral mechanisms underlie *C. elegans* aggregation and swarming. *eLife* 8: e43318. | *This paper identifies three interaction rules that link individual behavior to group-level phenotypes. Tuning these interaction parameters gives tight aggregates or dispersed group behavior that are experimentally observed. [6 citations]* |
| 9 | **Ding SS,** Woollard A. 2017. Non-muscle myosin II is required for correct fate specification in the Caenorhabditis elegans seam cell divisions. *Scientific Reports* 7: 3524. | *This paper identifies a novel role of nmy-2 gene in cell fate specification during developmental asymmetric cell divisions, which is independent of the primary polarity determination mechanisms. [2 citations]* |

277 *Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

*All publication and citation figures and metrics are based on Web of Sciences on May 31, 2021.*

*Dept./Group members in bold.*

*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*



## Max Planck Research Group Leader

# Serena Ding

+ PhD: 2016, University of Oxford, with Alison Woollard
+ Past positions: Postdoc, Imperial College London (2016-2021)
+ Joined MPI: 2021 as Max Planck Research Group Leader; non-tenured
+ Selected fellowships, grants & awards: Max Planck Research Group Leader (2020)
+ Lifetime publication record: 10 publications, 162 citations, h-index: 6
+ Mean hours of teaching per week during semesters at U KN: 0

## Genes and Behavior Group

**1** Number of group members

**0** Number of peer-reviewed publications

**100%** Percentage international group members

**100%** Percentage female group members

**0** Number of finished Doctoral Students

**0 BSc & 0 MSc** Number of finished students

**80,000 €** Third-party funding granted (CASCB)

# MAX PLANCK RESEARCH GROUP DEVELOPMENT AND EVOLUTION OF COGNITION

# MAX PLANCK RESEARCH GROUP DEVELOPMENT AND EVOLUTION OF COGNITION

## GROUP LEADER: CAROLINE SCHUPPLI

Cognition is selected for via cognitive skills and abilities, which provide individuals with fitness benefits (1). However, the larger brained a species is, the more individuals' skills and abilities depend on developmental inputs (2-4). Therefore, to understand the evolution of high-level cognition, we need to understand how skills and abilities develop in individuals. The focus of the Development and Evolution of Cognition Group lies on the development of cognitive performance, ecological skills, and cultural repertoires in orangutans and other large-brained species. We also look at broader patterns between life history, cognition, environmental, and social factors across a wider range of species.

## Research achievements

The Development and Evolution of Cognition Group started in February 2021. Over the past months, we have built up the team and finalized the planning for the upcoming doctoral and postdoc projects. This included establishing collaborations with multiple research institutions and field sites in Europe, the US, Indonesia, and Uganda, as well as collaborations with European zoos.

### LONG-TERM ORANGUTAN DATABASE

The Group's main data source is the data collected at the Suaq Balimbing research site in Indonesia, where we direct the orangutan research. With our technician team, we built and successfully tested a MySQL database, which will eventually contain long-term data on different aspects of the behavior of the Sumatran orangutans at Suaq, as well as data on their body size and growth, the nutritional content of their diet, and the site's environmental parameters. These data have been collected over multiple decades and data collection will be continued and expanded over the next years. We started data collection on the behavior and body size of orangutans housed in zoos following the same protocols as at Suaq. In combination, the data from the wild and captivity will allow us to investigate the effects of a large spectrum of developmental inputs on orangutan cognitive and behavioral development.

### LEARNING ECOLOGICAL SKILLS

In previous studies, we showed that immature orangutans acquire their ecological skills over multiple years (5) and through a combination of observational social learning and independent practice of the observed behavior (6, 7). Furthermore, opportunities for social learning during development were found to significantly affect social- and independent learning, as well as skill repertoires (9, 10). Building on these results, in our new study published in *Behavioral Ecology and Sociobiology*, we found that adult orangutan males and females differ in several aspects of their foraging behavior. Our results also showed that these behavioral differences start to develop during early immaturity and thus before they become physiologically relevant (11). In another study published in *PLoS Biology*, we found that immature orangutans have sex-specific attentional biases and learning outcomes through which they learn from individuals with the most relevant ecological knowledge (12).

*Figure II.27 – A juvenile female orangutan at the Suaq Balimbing research site, during her first encounter with the newly piloted apparatus for the experimental cognitive tests.*

### LEARNING AND ROLE MODELS

In our previous work on orangutan social learning (6, 7), the main focus was on the learning individual. With our technician and former Master's Student Mulati Mikeliban, we have now begun to look at the involvement of the role model. By analyzing a large cross-sectional data set on food solicitations of immature orangutans and their mothers, we showed that wild orangutan mothers adjust their behavior during food solicitations in a way that likely facilitates skill acquisition in their offspring (8). In continuation of our previous work on independent learning in wild orangutans (9), with the Group's technician and former Master's Student Anaïs van Cauwenberghe, we published a paper on the development of exploratory object manipulation behavior in wild immature orangutans (13). We found that orangutans learn about objects and the physical principles connected to them by progressing through a distinct developmental sequence, similar to the one observed in humans (e.g., 14).

## Future research agenda

The research goal of the Development and Evolution of Cognition Group is to understand the development of skills and abilities in individuals, to ultimately better understand the evolution of high-level cognition. To reach this goal, we will investigate how behavior, skills, and cognition in large-brained species develop under natural conditions and how individuals use their acquired skills in their daily lives, including navigating through their social and spatial environment. Furthermore, to reach the Group's research goal we will investigate the connection of cognitive development, skill acquisition, and life history across species. In light of these research goals, the following projects are now starting:

### LONG ORANGUTAN JUVENILITY

In our previous studies we have shown that during their eight-year dependency period, immature orangutans learn how to detect and process foods (5, 11). However, the dependency period is followed by a 6–8-year juvenile period before individuals start

reproducing. The lengthy juvenile period in orangutans could be explained by energetic constraints and/or the need to acquire additional skills and knowledge (4). As soon as the current pandemic situation will allow, Emma Lokuciejewski (Doctoral Student) will travel to the Suaq research site and start data collection for her doctoral project on different aspects of the physical and cognitive development of juvenile Sumatran orangutans. Lokuciejewski will collect data on ranging parameters, measures of social- and independent learning, as well as body size and growth. The results of this project are expected to elucidate the function of the long juvenile period in orangutans and potentially other large-brained species.

### TESTING APE COGNITION IN THE WILD AND CAPTIVITY

So far, we have relied on behavioral indicators to assess cognitive performance in wild orangutans (9, 10). One of our main research goals is to establish a cognitive test battery for wild and captive great apes (Figure II.27). The aim of this test battery is to experimentally assess several aspects of cognitive performance in a standardized way across species and settings. These tests are an integral part of the Volkswagen Freigeist Fellowship. This fellowship, obtained by Schuppli around the time of starting the Development and Evolution of Cognition Group, will help to significantly expand the Group. In the frame of this fellowship, two Doctoral Student projects will investigate the development of cognition and curiosity in wild orangutans and chimpanzees in different wild populations. A Postdoc project will focus on the development of cognition and curiosity as a function of different developmental factors in captive apes and in humans from different societies (Figure II.28).

### ORANGUTAN RANGING SKILL DEVELOPMENT

Furthermore, in collaboration with the established Groups at the MPI-AB, we will investigate how orangutans navigate through their home ranges in terms of optimizing food intake, travel distances, and nest locations. For this, we will use more than two decades of GPS data on ranging behavior collected at Suaq Balimbing. In combination with the detailed behavioral data collected during orangutan follows, and thanks to the species variable social system, we will have the unique opportunity to investigate how environmental and social effects influence the behavior of a wild great ape.

### REFRENCES

**1** Quartz, Sejnowski. 1997. *Behavioral and Brain Sciences* 20: 537-556; **2** Ross, Jones. 1999. *Comparative Primate Socioecology* pp 73-110; **3** van Schaik, Burkart. 2011. Social learning and evolution: the cultural intelligence hypothesis. *Philosophical Transactions of the Royal Society* B 366: 1008-1016; **4** Schuppli, et al. 2012. *Journal of Human Evolution* 63: 843-850; **5** Schuppli, et al. 2016. *Frontiers in Zoology* 13: 43; **6** Schuppli, et al. 2016. *Animal Behaviour* 119: 87-98; **7** Schuppli, van Schaik. 2019. *Foundations of Affective Social Learning* pp 24-40; **8** Mikeliban, et al. submitted; **9** Schuppli, et al. 2017. *Scientific Reports* 7: 15464; **10** Schuppli, et al. 2020. *Science Advances* 6: eaaw2685; **11** Schuppli, et al. 2021. *Behavioral Ecology and Sociobiology* 75: 1-14; **12** Ehmann, et al. 2021. *PLoS Biology* 19: e3001173; **13** Schuppli, et al. accepted. *Evolutionary Human Sciences*; **14** Muentener, et al. 2018. *Frontiers in Psychology* 9: 635.

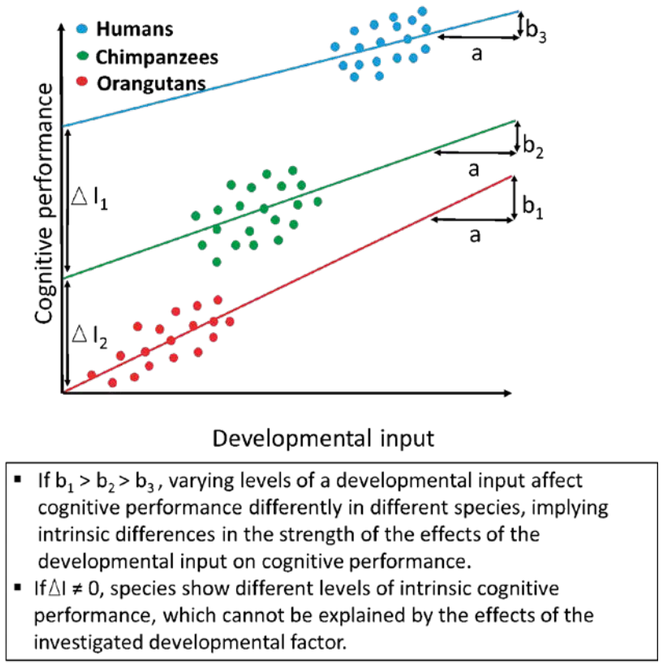



*Figure II.28 – Comparisons across and within species allow for investigating cognitive performance as a function of developmental inputs.*

# Highlights

## January 2021

Schuppli was awarded a Freigeist Fellowship by the Volkswagen Foundation, which will increase the 5-year budget of the Development and Evolution of Cognition Research Group by 42%.

## May 2021

Within the first four months of the Research Group, we successfully set up the Suaq long-term orangutan MySQL database and tested its functionality with the first 500 uploaded focal follows.

## May 2021

We published a paper in *PLoS Biology* on sex differences in social learning and learning outcomes in immature Sumatran orangutans (12).

## Most important publications


Ehmann B, van Schaik CP, Ashbury AM, Mörchen J, Musdarlia H, Atmoko SU, van Noordwijk MA, **Schuppli C.** 2021. Immature wild orangutans acquire relevant ecological knowledge through sex-specific attentional biases during social learning. *PLoS Biology* 19: e3001173.

*Immature orangutan males and females differ in their role model choice and learning outcomes in the foraging context. Whereas females preferentially observe their mothers, males show an increasing interest in foreign role models and adult males. [0 citations]*


**Schuppli C,** Atmoko SU, Vogel ER, van Schaik CP, van Noordwijk MA. 2021. The development and maintenance of sex differences in dietary breadth and complexity in Bornean orangutans. *Behavioral Ecology and Sociobiology* 75: 1-14.

*Flanged males and adult females differ in their daily and overall diet breadth as well as in their diet complexity. These behavioral differences start to develop during infancy, i.e., before they become physiologically relevant. [1 citation]*


**Schuppli C,** Van Cauwenberghe A, Setia TM, Haun D. 2021. The ontogeny of exploratory object manipulation behaviour in wild orangutans. *Evolutionary Human Sciences* 1-32.

*Immature orangutans learn about objects and the physical principles connected to them through exploratory object manipulations. They progress through a developmental sequence that resembles the one seen in human children.*


**Schuppli C,** van Noordwijk MA, Atmoko SU, van Schaik CP. 2020. Early sociability fosters later exploratory tendency in wild immature orangutans. *Science Advances* 6: eaaw2685.

*In immature orangutans, current exploration rates are correlated with levels of past experienced sociability. This suggests that even in the least sociable ape, cognitive performance is dependent on social inputs. [1 citation]*


**Schuppli C,** van Schaik CP. 2019. Animal cultures: how we've only seen the tip of the iceberg. *Evolutionary Human Sciences* 1: e2.

*The way animal culture has been measured so far did not allow for quantifying its diversity and prevalence. By directly counting socially learned skills, we reveal a wider spread across domains and larger cultural repertoires.*


*Altmetric donut and score: Visualization of the online activity surrounding the respective publication as of May 31, 2021*

*Open Access publication*

*Highly Cited Paper (Web of Science) performing in the top 1% of papers published in the same field in the same year.*

*All publication and citation figures and metrics are based on Web of Sciences on May 31, 2021.*

*Dept./Group members in bold.*

*Number of group members: junior and senior scientists, non-scientific staff*

*Number of finished students: as the first supervisor at U KN*

*Personnel numbers as of May 2021; all other numbers address the reporting period Jun 2017–May 2021.*



## Max Planck Research Group Leader

# Caroline Schuppli

+ PhD: 2016, University of Zurich, with Carel van Schaik
+ Past positions: Postdoc, University of Zurich (2016-2018), Postdoc, Leipzig University (2019-2020)
+ Joined MPI: 2020 as Max Planck Research Group Leader; non-tenured
+ Selected fellowships, grants & awards: Director of the SUAQ Orangutan Research Project, Indonesia (since 2017), SNF Postdoc Grant (2019), Max Planck Research Group Leader (2020), VW Foundation Freigeist Fellowship (2020)
+ Lifetime publication record: 19 publications, 298 citations, h-index: 11
+ Mean hours of teaching per week during semesters at U KN: 0

## Development and Evolution of Cognition Group

**5**
Number of group members

**4**
Number of peer-reviewed publications

**100%**
Percentage international group members

**60%**
Percentage female group members

**0**
Number of finished Doctoral Students

**0 BSc & 0 MSc**
Number of finished students

**817,000 €**
Third-party funding granted (Volkswagen Foundation)

# OUR PANDEMIC YEAR

## DISPATCHES FROM SCIENCE, STUDENTS, AND SERVICE.


### The great human pause

As the human world went into lockdown, we saw images of animals venturing out of the wild and into urban habitats. MPI-AB researchers also saw an unprecedented opportunity. In June 2020, a global team of researchers, including Mattias Loretto and Martin Wikelski, launched a bio-logging initiative to study wildlife before, during, and after the lockdown. Published as a commentary in *Nature Ecology and Evolution*, the team introduced a term—the Anthropause—to describe the global, temporary slowdown in human activity. They also outlined "urgent steps" for using this singular research opportunity to examine the impact of human presence and activity on wild animals.

### Lockdown in Latin America

In late March 2020, Claudio Monteza was visiting his home in Panama where he was spending a few months before flying to Germany to start a PhD with the MPI-AB. But days before he was to leave, life as he knew it changed. Panama imposed some of the strictest COVID-19 measures of any country, allowing its residents to leave home for only a few hours every week. Confined to his home and with his PhD plans in limbo, Monteza quickly pivoted to the new normal. By delivering online talks for local science agencies, he was able to acquire one of the country's few research permits that would allow him to work outside. Next, he needed a field vehicle, but with institute work cars out of bounds, Monteza pivoted again. "I went out and bought a beat-up car," he laughed. "Nothing's getting in the way of my PhD." Over the next 18 months, the student established camera trap surveys along roads, in the local forest, and in national parks. The data he single-handedly collected are revealing how roads affect wildlife movement, but also how wildlife is reacting to reduced human presence. "I'm so happy the pandemic inspired me to collect these data," he said. "Now I have a nice compliment to my original PhD project." Finally in Konstanz, Monteza is working on his next challenge: setting up a bank account in Germany.

### Support every day during the pandemic

The pandemic changed work for us all, but for the Administrative Technical Services, it required wholesale reimagining, from redefining core operations to sewing safety masks. And they did it without missing a beat. "The biggest success is that the team provided its service to our scientists every day during the pandemic," said Margit Plahl, Head of Admin. "There was no day of standstill." Much of this involved solutions to quotidian tasks, such as how to work with confidential HR and finance data from home, or how to continue husbandry for animals. But other duties plunged the team into the unknown. When travel restrictions hit in March 2020, the team had to coordinate evaluation flights for MPI-AB students from remote field sites around the world. The Welcome Office navigated the rapidly changing rules for scientists traveling to Germany and the required quarantine measures. To help, the MPI-AB guest house was transformed into an improvised quarantine facility for scientists coming from abroad, and staff assisted with transportation and grocery shopping. "We were confronted with the unknown, with the unforeseen," said Plahl. "But we know, even more so now, that we can count on each other no matter what."

**79,200**
Calculated number of person-hours in zoom meetings

**65**
New staff members starting during the pandemic

**Coffee consumption drop in Radolfzell**
2019 **100** KG
2020 **54** KG

**€ 125,365.75**
Support through extra 6-month contracts (IMPRS)

**334**
Masks sewn by and for MPI-AB staff

**42**
Weeks in obligatory home office

**685**
COVID-19 tests given out

**26**
People supported during quarantine

# THE INSTITUTE'S BACKBONE

## 3.1 Structure & Organization



## 3.2 Scientific Outreach



## 3.3 Infrastructure



## 3.4 Scientific Support



## 3.5 Career Support



## 3.6 Equal Opportunities



## 3.7 Public Engagement



## 3.8 Personnel Structure



## 3.9 Finances

The scientific output of the MPI-AB rests on a critical piece of infrastructure: the non-scientific personnel that underpin our daily operations. This underpinning includes the administration, animal holding, facility management, and IT services that are essential prerequisites to a world-class research environment. It also includes the career advancement, equal opportunity, and work-life balance initiatives that cultivate a positive culture of collaboration. In that sense, the infrastructure forged by our professional staff is nothing less than the backbone of our organization — and the foundation of its future.

# STRUCTURE AND ORGANIZATION

The reporting period 2017–2021 was marked by momentous organizational change. We saw the founding of our Institute in 2019, followed by rapid growth with the addition of a third Director, Meg Crofoot, as well as three Max Planck Research Groups. We further transferred several senior scientific staff to independent Group Leaders and installed transparent regulations for career options of our scientists and alumni.

Founded on June 1, 2019, the MPI of Animal Behavior was established to be a four-department institute, located in the lakeside city of Konstanz, dedicated to understanding and predicting animal decision-making in the natural world. At almost 300 members, the MPI-AB owes its early size and success to foundations laid on solid ground.

We emerged from the existing MPI for Ornithology (MPIO) based in Seewiesen, and so began operations with two full fledged Departments—led by Martin Wikelski and Iain Couzin—which continued from the MPIO sites in Konstanz and Radolfzell. A third Director, Meg Crofoot, joined the Institute immediately after its founding (Figure III.1). The fourth Department, planned to be filled once the Institute has transferred to its new building on the campus of the University of Konstanz in 2027, will complete our overall organizational vision. Our Directors' age structure guarantees the long term continuation of our vision, from Wikelski (retirement in 2032), to Couzin (2041), to Crofoot (2047).

The Institute's three Departments form the central axes from which the organizational structure extends (Figure III.2). The Directors constitute the Board of Directors, overseeing scientific and administrative core operations of the Institute. Alongside, the Managing Director leads ongoing affairs, such as representation of the Institute and financial reporting. The role of Managing Director has been held by Martin Wikelski since the Institute's founding, and this will transfer to Iain Couzin in June 2022 for the next three years. The Managing Director and the Board of Directors are in turn supported by the Head of Central Scientific Services; the Head of Administration & Technical Services; and the Science Coordinator.

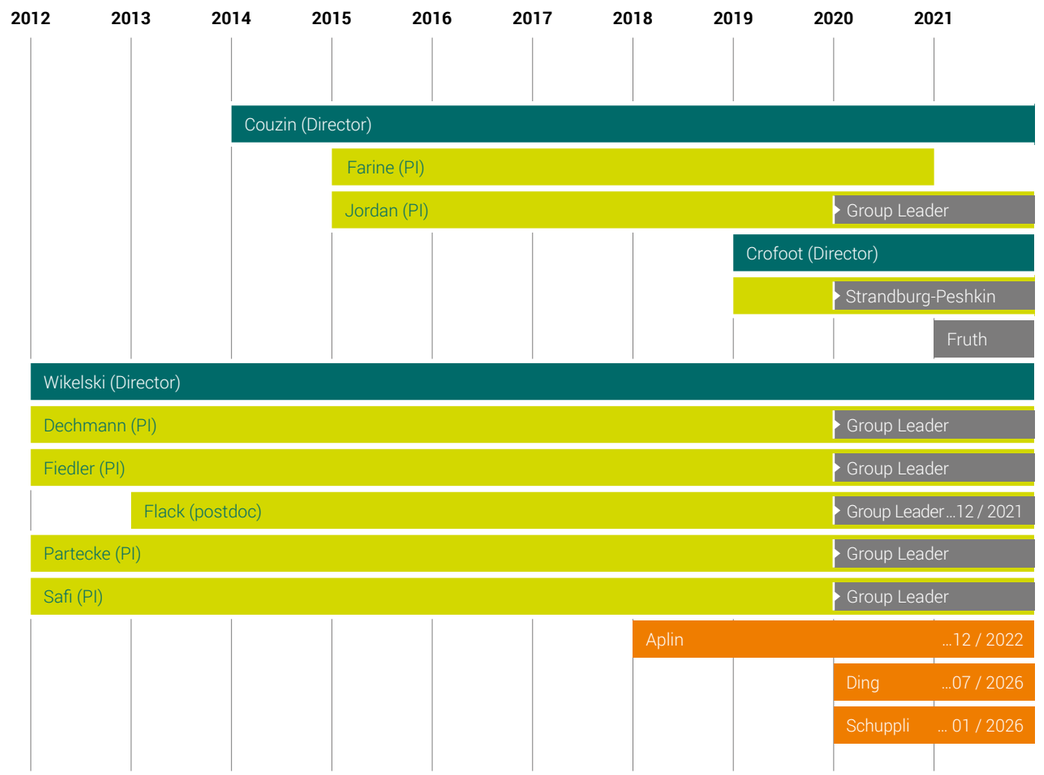



*Figure III.1 –*
*Directors (dark green), Max Planck Group Leaders (orange), and Group Leaders (grey) of the MPI-AB.*

## Group Leaders

Since its inception, MPI-AB has taken strides to realize its mission of creating an organization that empowers junior scientists and fosters inclusivity. This includes the implementation of the concept of Group Leader (GL) positions, initiated by the MPG's Biology and Medicine Section, which establish independent scientists within Departments. In August 2020 the Vice President Asifa Akhtar endorsed the MPI-AB proposal to transfer seven scientists to independent GL positions. An additional GL was endorsed in May 2021 (Figure III.1). This represents more than a change of title—it sets a benchmark for transparency in internal relations and parity among the Departments and scientific staff.

### THE FOLLOWING SCIENTISTS BECAME GLS IN THE REPORTING PERIOD:

+ In August 2020, Dina Dechmann, Wolfgang Fiedler, Andrea Flack, Jesko Partecke, and Kamran Safi were confirmed as GLs in the Wikelski Department
+ Alex Jordan in the Couzin Department
+ Ariana Strandburg-Peshkin in the Crofoot Department
+ Barbara Fruth was confirmed as GL in May 2021

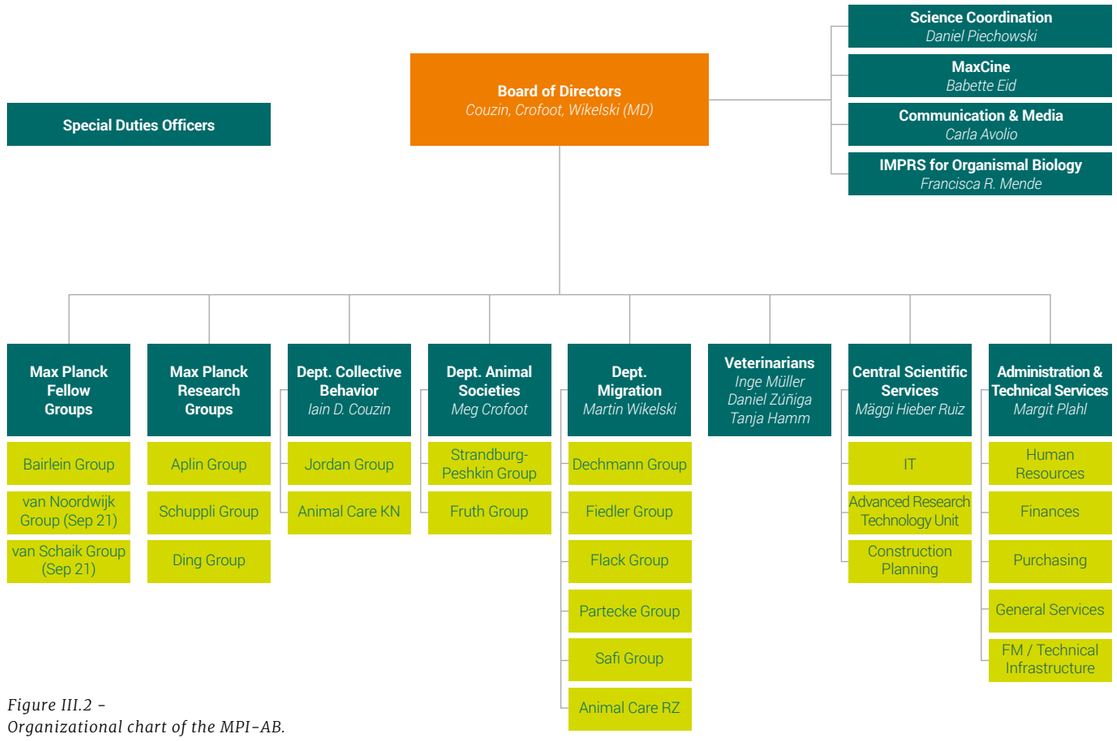



*Figure III.2 –*
*Organizational chart of the MPI-AB.*

## Max Planck Research Groups and Fellow Groups

Along with the Departments with their Directors and Group Leaders, the MPI-AB comprises an additional research unit: department-independent Max Planck Research Groups (MPRGs, Figure III.2). The Institute's first MPRG was established in 2018 by Lucy Aplin, who selected Radolfzell as her host institution following a successful application in the MPG's open-topic MPRG call. In the context of the Institute's founding a year later, the MPG granted two permanent, department-independent MPRGs. All three MPRGs are for five years with the option of 2+2 year extensions. The two new MPRG positions were advertised internationally and filled at the end of 2020.

NEW MPRGS WHO JOINED IN THE REPORTING PERIOD ARE:

+ Lucy Aplin started the Cognitive and Cultural Ecology Group in 2018
+ Caroline Schuppli, who leads the Development and Evolution of Cognition Group, started in 2021
+ Serena Ding, who leads the Genes and Behavior Group, started in 2021

The MPI-AB was also successful with applications in the MPG Fellow Program, which appoints active or recently retired university professors to lead small Fellow Groups at MPIs for three years.

NEW MPG FELLOWS ARE:

+ Franz Bairlein (formally Institute for Avian Research Wilhelmshaven) from 2020
+ Maria van Noordwijk and Carel van Schaik (both formally University of Zurich) from September 2021

## External partners

In a step towards cementing longlasting research relationships, we established Affiliate Scientist positions for alumni who have moved to a leading position at another scientific institution and with whom we continue to engage in scientific exchange. The Board of Directors decides on the temporary appointments that bring clearly defined rights and obligations for both sides. We were also successful in being awarded one Max Planck Tandem Group in Brazil and one Max Planck Partner Group in Colombia adding to the MP Partner Group in Bhutan, established in 2016. In addition to sharing talent and expertise, the collaboration afforded by all these external partners are an investment into the next generation. By building an international network of contacts and institutions, we build bridgeheads for our junior scientists into the global scientific community.

## Scientific Advisory Board and Board of Trustees

The scientific performance of the MPI-AB is evaluated by an international Scientific Advisory Board (SAB) every three years. The SAB is composed of internationally recognized scientists, reflecting the Institute's research spectrum. Feedback from the SAB helps the Institute to uphold the principles of the MPG—to conduct our research and support the research of others with integrity and according to the highest scientific standards. In addition to the SAB evaluation, the MPI-AB is advised by a Board of Trustees composed of members drawn from diverse backgrounds including politics, media, business, and the arts. The Board of Trustees seeks to strengthen the relationship between the Institute and the public, assuming a key role as ambassadors for Institute affairs and interactions with the Institutes' scientific and social environments. The Board of Trustees is planned to meet with the Institute once per year as soon as the COVID-19 pandemic measures will allow.

## MPI-AB and University of Konstanz collaboration

MPI-AB and U KN sustain a deep relationship grounded in longstanding partnerships on infrastructure, staff, and grants. Directors Couzin and Crofoot are full professors and Wikelski is now honorary professor after being full professor until 2016. Together with their Departments, they are intensely involved in university teaching and research. The University is the location for an entire MPI-AB Department (Couzin) as well as one of our core animal facilities (page 15); it currently pays 21 of our scientists and administered nearly € 3 million of our third party funding in the reporting period. (page 170).

IN THE REPORTING PERIOD, U KN AND THE MPI-AB COLLABORATED ON A NUMBER OF SUCCESSES ACROSS RESEARCH AND TEACHING:

+ Iain Couzin led successful applications to fund a building for Visual Computing of Collectives (VCC) and to establish the DFG Cluster of Excellence 'Centre for the Advanced Study of Collective Behaviour' (CASCB), which he co-directs.
+ The joint Doctoral program IMPRS for Organismal Biology, which has been running since 2009, graduated 10 Doctoral Students from MPI-AB during the reporting period (page 157).
+ All of MPI-AB's 15 most cited publications include authors with joint MPI-AB and U KN affiliations (Table III.1).
+ Negotiations began on an official cooperation agreement to formalize ongoing and future collaboration.

# SCIENTIFIC OUTREACH

Our scientists published an increasing number of peer-reviewed articles with a high impact in the scientific community. With co-authors from 83 different countries represented on all continents, our publications attest to the strength of MPI-AB's collaboration internationally. Pursuing our mission to produce rigorous and reproducible science that is shared openly, 75% of all articles published are open access.

## Scientific publications

Our scientists published 474 peer-reviewed journal articles with an MPI-AB affiliation during the reporting period. The number of publications per year increased continuously (Figure III.3) reflecting the growth of the MPI-AB. Among these articles, many were published in leading multidisciplinary journals, such as *Nature* (4x); *Science* (4x); *Nature Methods* (1x); *Nature Communications* (7x); *Science Advances* (7x); and *PNAS* (8x). The majority were published in subject journals, such as *Animal Behaviour* (26x); *Journal of Animal Ecology* (19x); *Methods in Ecology and Evolution* (12x); *Ecology and Evolution* (12x); and *Trends in Ecology and Evolution* (8x).

In addition to journal articles, MPI-AB scientists published several books and reports including faunas (1, 2); regional and continental censuses (3, 4); and Red Lists (e.g. 5). By forming the basis of legislative activities on the state, national, and EU-level, they have strengthened the impact of our research beyond academia.

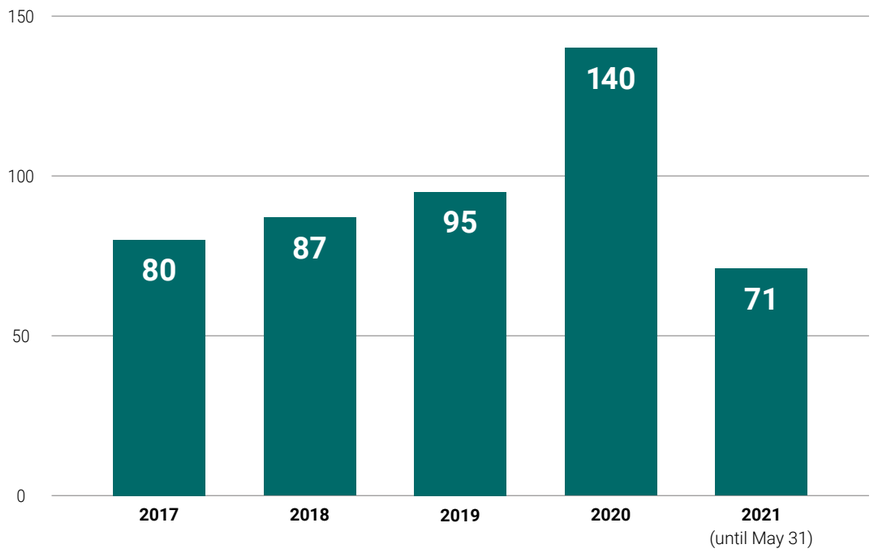



*Figure III.3 – Number of MPI-AB publications during the reporting period.*

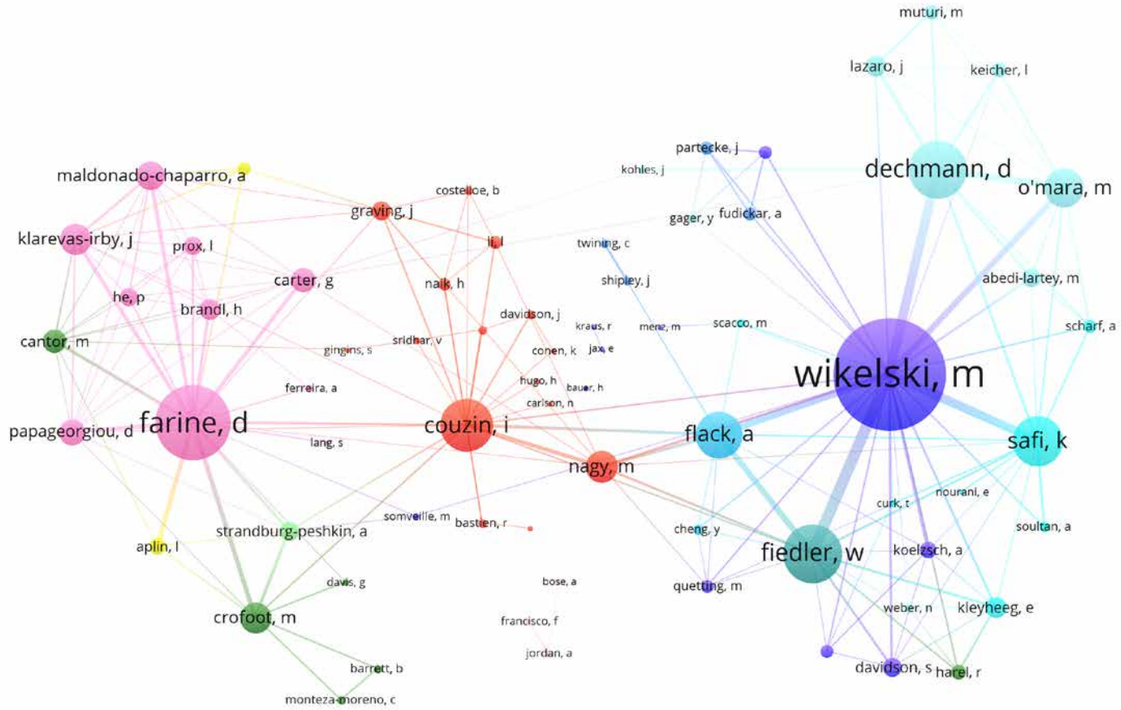



*Figure III.4 – Publication network with multiple MPI-AB co-authors. (link strength=number of joint publications; node size=total link strength; color=Dept./Group; only authors with two or more publications are considered).*

## Open Access (OA)

The MPI-AB is committed to the public and free availability of our scientific results. For this reason, 75% (355) of all articles are open access. About 30% of all OA articles were published in true OA journals (OA Gold) and this rate remained stable over the reporting period. The OA journals with the greatest number of our publications were *Scientific Reports* (18x); *Royal Society Open Science* (16x); *Ecology and Evolution* (12x); *PLoS ONE* (11x); and *eLife* (8x). The share of OA Green publications (i.e., the article is behind a paywall but the manuscript can be obtained from a repository) decreased from over 50% in 2017 to about one-third in 2020. This is related to the strong increase in OA Hybrid publications: in this case, the article has appeared in a regular subscription journal but has been made publicly available by paying processing fees.

OPEN ACCESS SUCCESS DURING THE REPORTING PERIOD:

+ 75% (355) of all articles are open access.

+ The share of OA Hybrid publications increased significantly resulting from the OA contracts concluded centrally by the MPG with major publishing houses. Therefore, the MPI-AB does not incur any costs for OA publications in hybrid journals.

+ The 15 most cited articles of the reporting period (Table III.1) have been openly accessible from the time of publication.

## Collaboration

The 15 most cited articles of the reporting period (Table III.1) further illustrate MPI-AB's progress in open science, as well as our strength in international cooperation. Eight publications list seven or more authors each (Tucker et al. with 115 co-authors), most of whom work in institutes across the globe (seven of those papers list affiliations from at least four different countries). In total, papers published over the entire reporting period were co-authored with scientists at institutions from 83 countries. Co-authors, while mostly based in Europe or the USA, are represented by institutions from all continents. This is especially true for co-authors based in countries where we conduct fieldwork and have longstanding ties, e.g., Bhutan, Ecuador, or Kenya (Figure III.5)

Such cooperation extends to the Institute level, as evidenced by several joint publications across MPI-AB Groups and Departments (Figure III.4). MPI-AB has made investments to create the conditions for such collaboration to emerge, not by chance, but in a very targeted manner. The Science Coordination unit, for example, promotes internal communication and exchange via a newsletter, seminar series, and scientific retreats. The newly established Advanced Research Technology Unit (page 155) aims to develop and apply emerging technological and analytical tools to be utilized across Departments and Groups and to establish a bottom-up pathway to cross-departmental connections through in-depth collaboration with scientists working on similar questions.

### NOTABLE INTERNAL COLLABORATIONS INCLUDE:

**+** A highlight for internal collaboration is the project investigating collective migration of white storks driven by Andrea Flack and Máté Nagy. Here, the biological and technological know-how of Flack, Fiedler, and Wikelski was combined with the analytical skills of Nagy and Couzin, resulting in three publications including a highly cited paper in *Science* (6-8).

## Scientific conferences

The MPI-AB has made headway in putting our young Institute on the world map as a location for the study of animal behavior. We hosted and organized two large international scientific conferences in Konstanz: the 6th International Bio-Logging Science Symposium (2017) and the summer conference of the Association for the Study of Animal Behaviour (2019). Combined, these two meetings were attended by approximately 800 participants of which 75% came from abroad.

Additional to these two large conferences, we organized the summer school AniMove as well as the Social Network Analysis Workshop (SNA). AniMove is a 2-week long intensive course for 20 participants from all over the world to learn how to analyze animal movement data and to combine it with remote sensing environmental data. Kamran Safi and his Group are running AniMove together with colleagues from European institutions and the Smithsonian. During the reporting period, AniMove took place at the MPI-AB in 2017 and 2018, and at the Smithsonian and Yale University in 2019. The course scheduled at the MPI-AB for 2020 had to be canceled. The SNA is a three-day course to develop an understanding of fundamental methods for animal social network analysis organized by Damien Farine and his lab. During the reporting period, they organized this course three times at the MPI-AB for 30 international students each.

### REFERENCES

**1** Hölzinger, Bauer. 2018. *Die Vögel Baden-Württembergs: Dendrocygnidae (Pfeifgänse)-Anatidae (Entenvögel)*; **2** Hölzinger, Bauer. 2021. *Die Vögel Baden-Württembergs: Greifvögel*; **3** Bauer, et al. 2019. *Vogelwelt* 139: 3-29; **4** Keller, et al. 2020. *European Breeding Bird Atlas 2: Distribution, Abundance and Change*; **5** Ryslavy, et al. 2020. *Berichte zum Vogelschutz* 57; **6** Flack, et al. 2018. *Science* 360: 911-914; **7** Nagy, et al. 2018. *Philosophical Transactions of the Royal Society* B 373: 20170011; **8** Klein, et al. 2019. *Journal of the Royal Society Interface* 16: 20180794

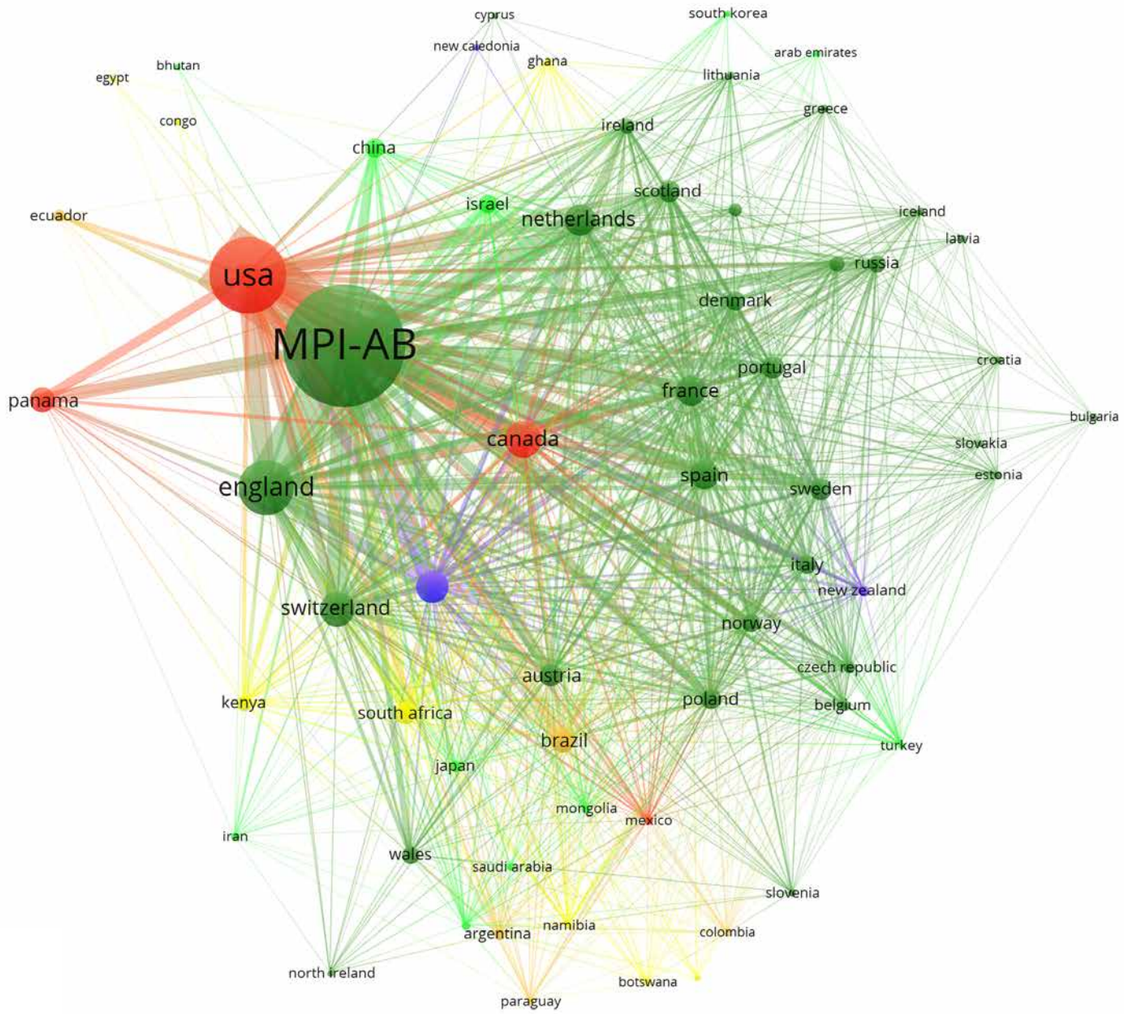



*Figure III.5 –*
*Publication network with the countries of institutions of co-authors on MPI-AB publications. (link strength=number of joint publications; node size=total number of publications; color=continent; only countries with two or more publications are considered).*

*Table III.1 –*
*Most cited MPI-AB publications from the reporting period (Number of citations based on Web of Science; MPI-AB authors in bold; * affiliated with MPI-AB and U KN). Note that this list is biased towards papers published early during the reporting period as well as towards scientists with already established labs at the MPI-AB.*

| CITATIONS | AUTHORS | YEAR | TITLE | JOURNAL | DEPT. / GROUP |
|---|---|---|---|---|---|
| 298 | Tucker + 114 co-authors incl. **Blake**, **Davidson**, **Fiedler**, **Hurme**, **LaPoint**, **Safi**, **Wikelski** | 2018 | Moving in the Anthropocene: Global reductions in terrestrial mammalian movements | *Science* | Fiedler, Safi*, Wikelski* |
| 125 | **Farine** | 2017 | A guide to null models for animal social network analysis | *Methods in Ecology and Evolution* | Farine* |
| 113 | **Jolles**, Boogert, **Sridhar**, **Couzin**, Manica | 2017 | Consistent individual differences drive collective behavior and group functioning of schooling fish | *Current Biology* | Couzin* |
| 98 | Thorup, Tøttrup, Willemoes, Klaassen, Strandberg, Vega, Dasari, Araújo, **Wikelski**, Rahbek | 2017 | Resource tracking within and across continents in long-distance bird migrants | *Science Advances* | Wikelski* |
| 84 | Rahwan + 22 co-authors incl. **Couzin** | 2019 | Machine behaviour | *Nature* | Couzin* |
| 83 | Rutz + 14 co-authors incl. **Loretto**, **Davidson**, **Wikelski** | 2020 | COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife | *Nature Ecology & Evolution* | Wikelski* |
| 74 | Stowers + 11 co-authors incl. **Bastien**, **Couzin** | 2017 | Virtual reality for freely moving animals | *Nature Methods* | Couzin* |
| 52 | Hoppit & **Farine** | 2018 | Association indices for quantifying social relationships: How to deal with missing observations of individuals or groups | *Animal Behaviour* | Farine* |
| 52 | Miller, **Farine**, Trisos | 2017 | Phylogenetic community structure metrics and null models: A review with new methods and software | *Ecography* | Farine* |
| 50 | Didham + 12 co-authors incl. **Menz** | 2020 | Interpreting insect declines: seven challenges and a way forward | *Insect Conservation and Diversity* | Wikelski* |
| 47 | **Graving**, Chae, **Naik**, **Li**, **Koger**, **Costelloe**, **Couzin** | 2019 | DeepPoseKit, a software toolkit for fast and robust animal pose estimation using deep learning | *eLife* | Couzin* |
| 47 | Berdahl, Kao, **Flack**, Westley, Codling, **Couzin**, Dell, Biro | 2018 | Collective animal navigation and migratory culture: From theoretical models to empirical evidence | *Philosophical Transactions of the Royal Society B* | Couzin*, Flack* |
| 47 | **Flack**, **Nagy**, **Fiedler**, **Couzin**, **Wikelski** | 2018 | From local collective behaviour to global migratory patterns in white storks | *Science* | Couzin*, Fiedler*, Flack*, Wikelski* |
| 47 | **Strandburg-Peshkin**, **Farine**, **Crofoot**, **Couzin** | 2017 | Habitat and social factors shape individual decisions and emergent group structure during baboon collective movement | *eLife* | Couzin*, Crofoot, Farine*, Strandburg-Peshkin |
| 45 | Sánchez-Tójar, Schroeder, **Farine** | 2018 | A practical guide for inferring reliable dominance hierarchies and estimating their uncertainty | *Journal of Animal Ecology* | Farine* |

# INFRASTRUCTURE

A rapidly growing institute located in a heritage town requires creative space solutions. With rooms in Radolfzell and the university in short supply, the MPI-AB pivoted to a new office block in Konstanz to accommodate Meg Crofoot's new Department and our growing staff in early 2020. But an ultimate solution was on its way. In September 2020, funding for a € 60 million building was secured for the Institute's future home—a space for 300 people, plus animal facilities and labs, on the U KN campus. Expanding on existing infrastructure, the MPI-AB also delivered new capabilities for its mission to apply emerging technologies to understand behavior in the natural world. The Institute unveiled one of the largest ultra-high resolution imaging facilities in the world, and ramped up investments in naturalistic experimental facilities and remote field operations.

## Space and locations of the Institute

A result of the Institute's continuous growth is that Departments and Groups are currently distributed over three different locations—Radolfzell, the University of Konstanz, and Bücklestrasse in Konstanz—with approximately 22 km distance between Radolfzell and Konstanz (Figure III.6). The initial Institute building in Radolfzell still houses the major part of Administration and Technical Services as well as the Department of Migration, headed by Martin Wikelski. Due to his main appointment as full professor at the University of Konstanz, Iain Couzin established his Department of Collective Behavior on the university campus. The Department for the Ecology of Animal Societies, started by Meg Crofoot in 2019, rented additional office space in the city of Konstanz due to space shortages in the Institute building in Radolfzell and the University of Konstanz.

The available space (at all locations) increased from 3,645 $m^2$ in 2017 to almost 6,000 $m^2$ in 2021 (Figure III.7). The biggest increase was in office space, due to Meg Crofoot's initial space allocation at the university campus in 2019 combined with the move in 2020 with other Research Groups into the third location at Bücklestrasse. In 2021, Iain Couzin and his team moved from one building on the university campus to the newly constructed 'Centre for Visual Computing of Collectives' (VCC) on the university campus with more office and animal facility space.

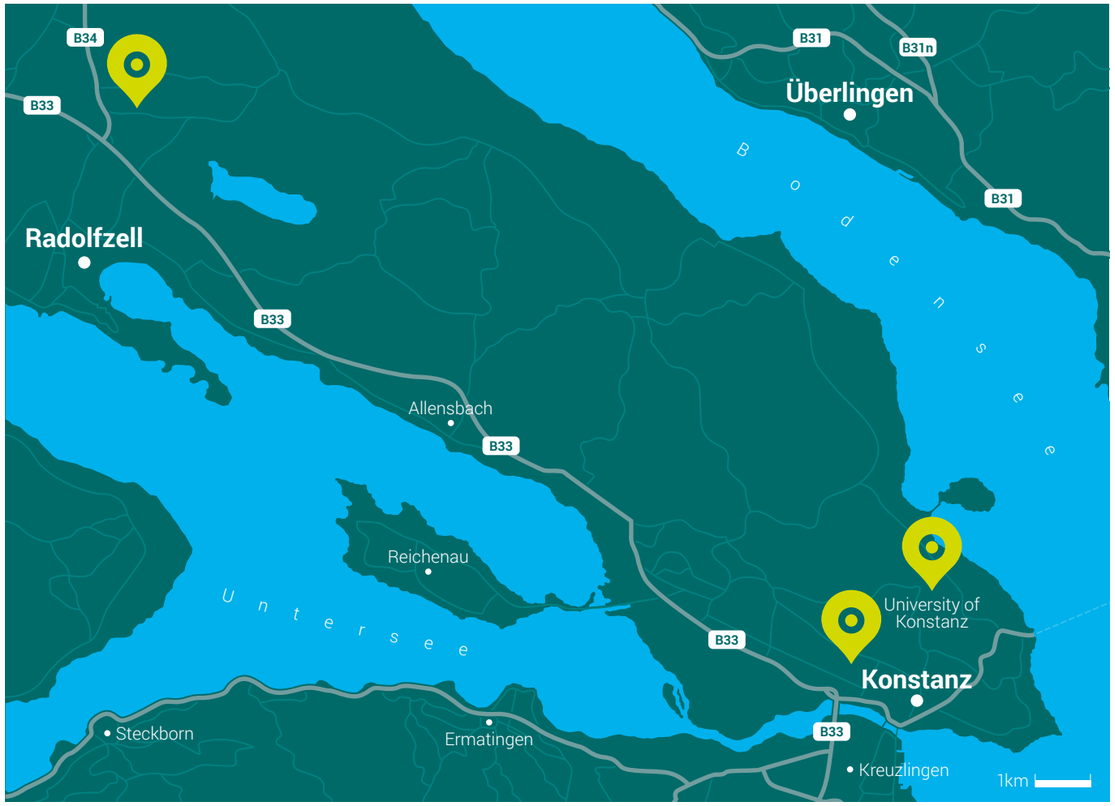



*Figure III.6 – Distribution of the three Institute locations in Radolfzell-Möggingen and Konstanz.*

## A single home for MPI-AB

Following the recommendations of the last SAB evaluation, all Departments, Research Groups, and central services will move into one Institute building on the university campus, likely in 2027. Funding of the € 60 million building was secured from the state of Baden-Württemberg in September 2020 and approved by the Joint Science Conference of the federal government and the states (GWK) in April 2021. The new building will be constructed on the western part of the parking lot on the university campus and will offer 3,000 $m^2$ office space for over 300 people; nearly 1,900 $m^2$ animal facilities and 300 $m^2$ laboratory space; as well as ample space for communication, meetings and child/parent offices. It will finally allow all scientists and staff members of the Institute to be at one location, facilitating exchange and collaboration between all Departments and Groups. The Radolfzell-Möggingen facility will be maintained as a field station thus preserving the well-established aviaries and animal facilities for future use.

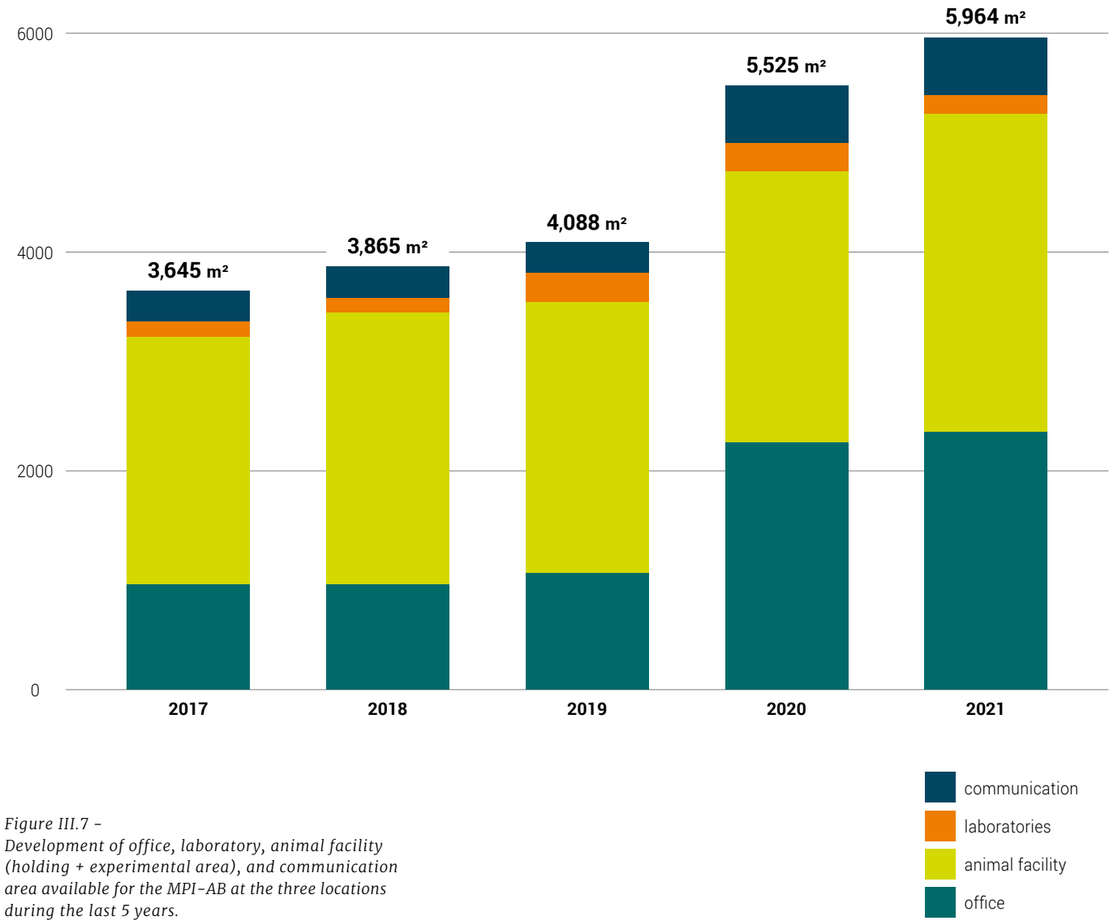



*Figure III.7 –*
*Development of office, laboratory, animal facility (holding + experimental area), and communication area available for the MPI-AB at the three locations during the last 5 years.*

## Scientific infrastructure

The scientific infrastructure is mainly located at the Institute building in Radolfzell and the U KN. It includes the animal facility, comprising holding and experimental areas, as well as laboratories and state-of-the-art tracking facilities (Table III.2). Our close cooperation with the U KN also facilitates the use of their core facilities such as the new pre- and post-DNA labs in the VCC, the scientific workshop, or the mesocosms for fish holding in their Limnological Institute.

NEW, UNIQUE FACILITIES FOR STUDYING NATURALISTIC INTERACTIONS OF GROUPS ARE:

+ The Imaging Barn, constructed in 2017–18 inside a traditional 18th-century barn at Radolfzell, served as a prototype for the larger Imaging Hangar in the basement of the VCC.

+ The Imaging Hangar began operation in June 2021 as one of the largest facilities of its kind globally. Both halls are operated in cooperation with the Center for the Advanced Study of Collective Behavior (CASCB) at the U KN. Enabled by current and future technological advances in the areas of sensor-, processing-, and projection technology, it will be possible to conduct quantitative behavior analyses of whole groups of freely moving animals.

## Facility maintenance and construction

Facility management at the Institute consists of 2.5 people and is not only responsible for building services but also for the construction and modification of the scientific infrastructure. Major activities in the reporting period include the construction of the Imaging Barn; renovation of the obsolete operation room; mosquito protection for the aviaries; and fire prevention and safety measures. Expenses for maintenance and construction varied between € 314k–750k per year depending on the respective tasks. The construction of the Imaging Barn was managed by the MPG and expenses have been covered centrally.

## Institutional field and transportation options

Two of the Departments and two of the MPRGs conduct a major part of their experiments in the wild. The MPI-AB supports this study of animal behavior in natural environments by providing several transportation options for field experiments remote places. These include a small Cessna aircraft and an ultralight plane for training birds; tracking flying animals such as birds, bats, or insects; and measuring environmental and atmospheric conditions related to animal movement. Additionally, the Institute provides a motorboat on the adjacent Lake Constance to track water birds and fish, as well as several field vehicles at the Institute locations and international field sites.

*Table III.2 –*
*Main scientific infrastructure of the MPI-AB at the two locations in Möggingen and the university campus.*

| SCIENTIFIC INFRASTRUCTURE | RADOLFZELL | VCC, UNIVERSITY CAMPUS |
|---|---|---|
| **ANIMAL FACILITY, INCL. HOLDING, EXPERIMENTAL + ANCILLARY SPACE** | 196 rooms (2,225 m²)<br>for birds and small mammals | 22 rooms (686 m²)<br>for insects and fish |
| **LABORATORIES** | 2 laboratories (46 m²) | 4 laboratories (120 m²) |
| **IMAGING SPACE** | Imaging Barn (97 m²)<br>14,7 x 6,6 x 6 m | Imaging Hangar (209 m²)<br>15,1 x 13,9 x 8 m |

# SCIENTIFIC SUPPORT

The Scientific Services offered by the MPI-AB are essential for the functioning of our Institute. These services include animal holding with animal welfare and the veterinarian services; IT; the Advanced Research Technology (ART) Unit; construction planning; outreach and media relations; laboratory and library services; science coordination; and the coordination of our graduate school, the IMPRS for Organismal Biology.

## Personnel growth

The Scientific Services grew from 21 people (equal to 17 full time equivalent) in 2017 to 38 people (=31 full time equivalent) in 2021, mainly by a strong increase in animal holding, IT, and the establishment of the new ART Unit (Figure III.8). For further support, we work closely with the scientific services at U KN, such as their Scientific Engineering Services, the Communication, Information, Media Center (KIM), or the Research Support Unit.

## Animal facilities

Our Institute's vision is to understand and predict animal decision-making in the natural world, and so we offer animal holding facilities that provide naturalistic environments. These include outdoor aviaries for birds and large fish tanks with enriched natural environments housing fish schools. Animal holding constitutes the biggest service area, comprising 18 people (equal to 14.5 FTE) and over 2,200 m² of aviaries, fish tanks, and experimental and auxiliary space at two locations (page 146).

### RADOLFZELL

Animal holding at Radolfzell is composed of nearly 200 holding and experimental rooms, most of them outdoor aviaries designed to keep birds under semi-natural conditions. Some are designed to house small mammals e.g., common shrews and bats. This unique facility allows researchers to run a variety of experiments comprising captivity and free-living components. Following the Institute's  move to its new building on the university campus, likely in 2027, these facilities will continue operations as a field station.

NOTABLE DEVELOPMENTS AND PROJECTS IN THE RADOLFZELL ANIMAL FACILITIES INCLUDE:

+ The Partecke Group and animal facility staff have succeeded in the remarkably challenging task of breeding captive passerines in semi-natural conditions. Applying a management plan that includes hygiene measures, prophylactic, and medical care, the facility breeds around 200 juvenile blackbirds per year. This infrastructure supports the Parteke Group's large common garden experiment using European blackbirds to disentangle the intrinsic and extrinsic mechanisms that control bird migration (page 94).

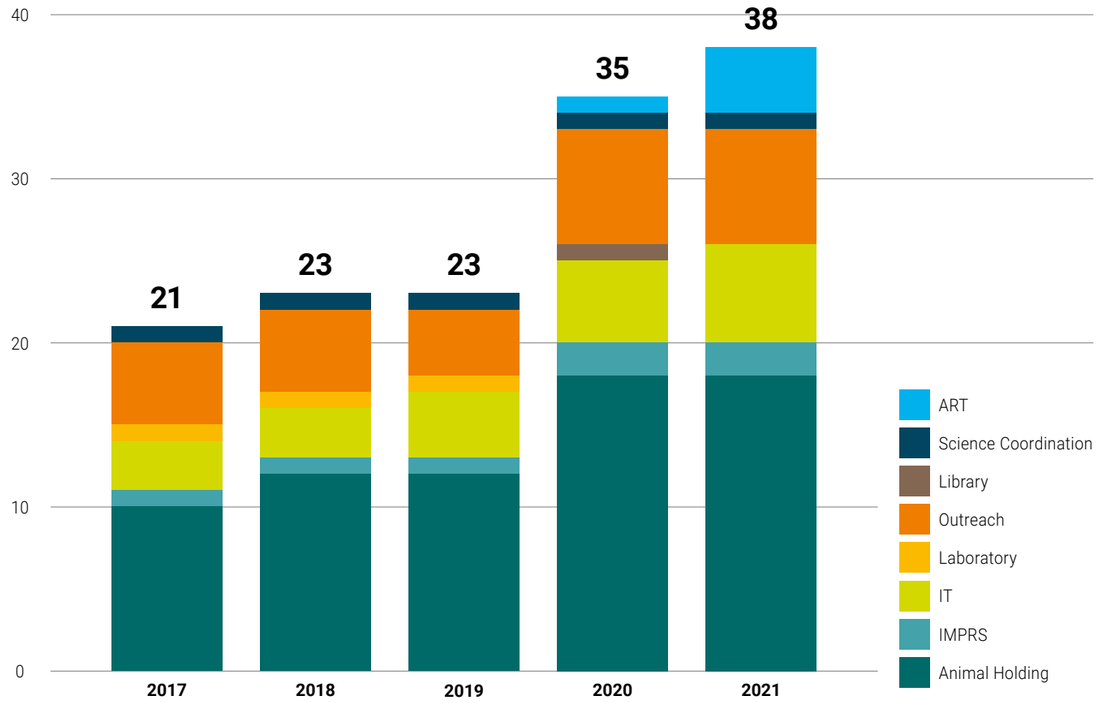



*Figure III.8 – Development of personnel in Scientific Services.*

+ A temporary outdoor holding arena was built to keep wild caught common shrews throughout the year under natural conditions. The structure supports research by the Dechmann Group to study the seasonal brain shrinking and regrowth of individuals (page 76).

+ Renovations of several rooms have expanded research capabilities; for example, a new observation room added to the aviaries can be used to run behavioral assays or training experiments by the Aplin Group (page 108).

+ The surgery room has been fitted with a proper ventilation system that is integrated with a new surgery table to reduce the concentration of waste isoflurane. This surgery room does not only support operations for sick animals, it also supports medical procedures that are required for research, such as implantation of heart and temperature loggers; corticosterone implants; and X-ray imaging.

### UNIVERSITY OF KONSTANZ

Animal holding at the U KN provides indoor holding and experimental space focusing on fish and insects. The animal holding facility is currently moving to the new VCC building with nearly 700 m² for animal holding and experimental space. This new facility is equipped with state-of-the art fish breeding facilities as well as experimental infrastructure for high-resolution recording and observation of individuals and collectives.

## Animal welfare

Due to basic differences and spatial segregation, the animal facilities in Radolfzell and Konstanz are treated as two separate entities in their legal status. As a consequence, the Institute has two Ethical Committees (legally required "Tierschutzausschuss"), each consisting of the Animal Welfare Officers; the respon-

sible persons for animal facilities; head and deputy of the animal care team; and, when necessary, Institute members and the scientists performing experiments.

The MPI-AB aims to study the natural behavior of animals and thus we take great care to reduce human impact and stress. All animal husbandry and experiments are approved by the Regierungspräsidium Freiburg, the state's ethical commision responsible for our region. During the last four years, a total of 57 animal experiments to study 44 animal species within Germany have been approved. The use of animal husbandry at the MPI-AB is defined by a respective regulation for each location. Our animal husbandry follows the principle of the "4 Rs". The number of animals kept and bred must be limited to the necessary minimum (Reduce) and the keeping conditions must be optimised (Refine). The least developed animal species should be chosen or, if possible, alternative methods should be used (Replace). All employees in animal husbandry have a special Responsibility for the welfare and health of the animals kept.

Studying such a variety of animal species in naturalistic settings or the species' natural environment requires extra training that is currently not available at any certified animal ethics course. In addition to existing courses offered by external professionals, the MPI-AB Animal Welfare Officers have implemented in-house training for our scientists and animal care personnel in research-specific topics. The long-term objective is to offer quality (FELASA certified) in-house training, custom made for the Institute, that covers the main species which are the subject of our animal experiments.

### SUCCESSFULLY IMPLEMENTED ANIMAL WELFARE COURSES INCLUDE:

+ A modular course on laboratory animals according to the guidelines of the Federation of European Laboratory Animal Science Associations (FELASA) and the "3R-Principle", including a specific zebrafish module.

+ An ethics in animal science workshop providing an ethical and legal framework for junior scientists for writing an animal experiment application.

+ An animal ethics course on specific German legal framework of animal experimentation, including general biology and husbandry condition (fish and birds); anesthesia and euthanasia; pain recognition and suffering; and severity classification.

+ Regular courses on the ringing and handling of trapped birds organized by the MPI-AB Center for Animal Marking (page 82), which are open to amateurs, students, and Institute members.

As one of the leading institutes in animal tracking, the MPI-AB has a special responsibility to further develop the ethical background of this technology. For the use of animal-attached devices, this involves a constant ethical evaluation of the scientific benefits versus costs for animals. It also includes refinement of the tracking technology and promoting the miniaturization of tags into smaller and lighter devices.

### INITIATIVES TOWARDS REDUCING THE IMPACT OF EXPERIMENTS INCLUDE:

+ Facilities such as the Imaging Hangar and large fish observation tanks allow for marker-less tracking of experimental animals.

+ Several Artificial Intelligence tools have been developed to record and analyze behavior of individual animals in large groups without the use of markers, and many are already being applied in field studies. Alex Jordan, for example, uses machine-learning based tracking to study the behavior of freely moving fishes in the wild (page 42).

+ A robotic system, comprising bio-mimetic fish swimming in a flow tank, was developed by scientists from the Couzin Department for empirically studying swimming hydrodynamic interactions in fish schools (page 32).

Public Engagement and an open culture to present and discuss our research to the public is a key element of the Institute. Information about animal experiments at the Institute is regularly given at guided Institute tours and ethical issues of tracking are brought up whenever this falls under the focus of the tour. Whenever possible, without stressing our animals or violating hygiene measures, the guided tours can also visit part of our animal facilities. Our animal facilities and research projects have been presented in various media productions (page 162).

During the reporting period, the commitment and experience of our personnel were recognized by the appointment of our Animal Welfare Officer as a member of the Expert Pools of the German National Committee for the Protection of Lab Animals used for Scientific Purposes; and the certification of our responsible person for animal facilities as a VIRT2UE Trainer for research integrity and ethics by the Embassy of Good Science.

# Information Technology (IT)

The IT unit administers infrastructure and supports our scientists in research-specific IT issues. MPI-AB's separate locations, with differing requirements and conditions, present a particular challenge to implementing IT solutions. Many of our research projects are based on high-resolution recordings producing large amounts of data that need to be stored, processed, and archived. The volume of produced data increased more than 20-fold within the last four years. To meet this demand, we installed storage as well as fast data connection between the different locations and our external partners. Our IT team, currently consisting of five people and one apprentice, closely collaborates with the IT team from U KN as well as with services offered by the MPG. These include the Max Planck Computing and Data Facility (MPCDF), which provides up-to-date infrastructure for data management including long-term archival; and the GWDG, which is the data and IT service center of the MPG.

### KEY DEVELOPMENTS IN IT INCLUDE:

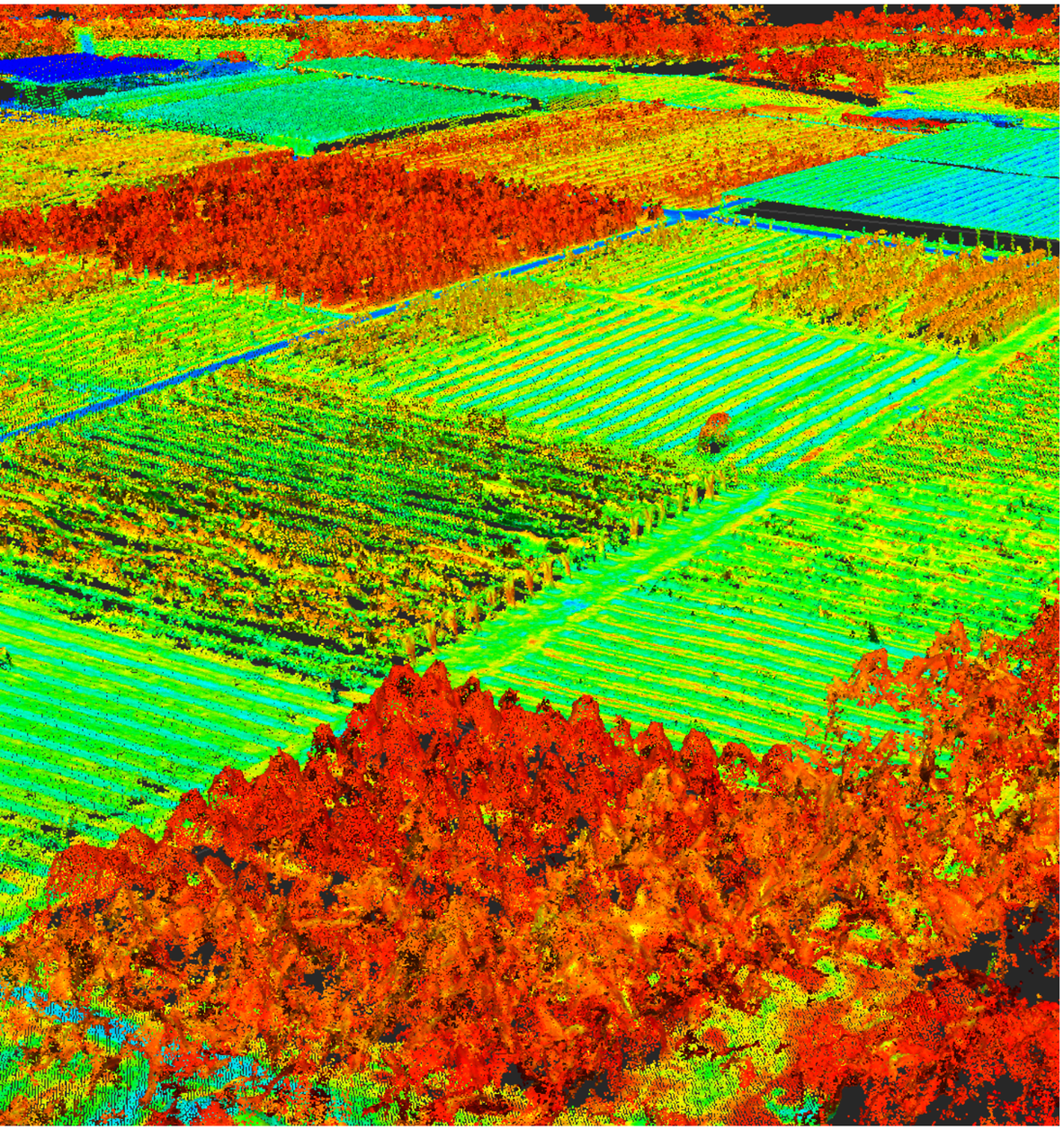
+ Both existing storage servers have been extended each by 300 TB to compensate for the increasing volume of produced data.

+ Labs and offices have been equipped with a 10G network, connected since 2019 via an exclusive 10G connection to the MPCDF.

+ Installation of more than 40 recording and video workstations in cooperation with Loopbio, an external developer of high throughput video recording systems, animal tracking software, and virtual reality assays.

+ Equipment of the Imaging Barn with a unique, high-resolution tracking and recording system using 28 IR cameras for marker-based and 5 RGB cameras for markerless tracking.

*Imaging Hangar*



*NDVI (Normalized Difference Vegetational Index) over an apple orchard taken by the ART Unit.*

## Science Coordination

Unifying the parts of MPI-AB and binding them to forge a world-class research environment requires an investment into internal communication and coordination. The Science Coordinator and the Head of the Central Scientific Services are a key node connecting the scientists, services, and administration. This role takes on added importance for the Institute, which has seen a rapid increase in employees, expansion into three distinct locations, and Departments and Groups that range from well-established to brand new. The Science Coordination office aims to establish a joint framework for the Institute's research and science; to offer a holistic teaching and career development program from Bachelor and Master's to Doctoral Students to Postdocs and Group Leaders; and to establish the MPI-AB as a lighthouse in the scientific community.

NEW INITIATIVES OF THE SCIENCE COORDINATION OFFICE INCLUDE:

+ Supporting all Directors in management duties.

+ Establishing a strategy and concept for MPI-AB research grounded in the Institute's Vision and Mission statement.

+ Being the point of contact for scientific support, such as advice in grant applications and career planning.

+ Stimulating internal communication and information flow by annual scientific retreats, weekly newsletters, a seminar series, and development of an intranet.

+ Complementing the IMPRS to support junior scientists and Group Leaders in their career development.

+ Offering special duties support on Institute relevant topics such as the Nagoya protocol or data protection.

## Advanced Research Technology (ART) Unit

The MPI-AB strives to establish itself as a leader in animal observation technology development and the respective analysis and synthesis of resulting data. This technology development is critical to our mission to understand and predict animal decision-making in the natural world. The Institute responded by establishing the Advanced Research Technology (ART) Unit—a group of central scientists who support all MPI-AB researchers to develop and adopt emerging technologies and methods. A key goal for the ART unit is to establish a bottom-up pathway to cross-departmental collaboration by bringing together scientists working on similar questions. By doing so, ART hopes to foster a culture of collaboration across diverse scientific disciplines, and to preserve institutional knowledge for future generations.

*IMPRS meeting*

# CAREER SUPPORT

The MPI-AB is committed to creating an environment in which junior scientists can realize their potential, be it in academic careers or beyond. Career support at the Institute covers every step of the academic ladder, from teaching and supervising undergraduates; to enrolling our Doctoral Students in the International Max Planck Research School (IMPRS) for Organismal Biology; to supporting our Postdoctoral researchers and Group Leaders. Added to this are a wide assortment of professional development offers; mentoring programs; awards and distinctions; and networks. We have continuously refined our support structures for career paths, and we offer binding contracts of employment, even for the early stages of a career. We further uphold the Rules of Good Scientific Practice adopted by the MPG in 2000. This is a commitment to limiting scientific misconduct and creating a culture in which high quality science is conducted on equal footing.

## Teaching

While not a teaching institute per se, MPI-AB is an active partner in teaching at the U KN, connecting students to top-level research opportunities from early in their studies. All three Directors hold a full-time or honorary professorship and, together with our Group Leaders, are directly involved in teaching and supervising Bachelor and Master's students. MPI-AB courses include a lecture at the Bachelor level as well as three advanced courses (each, a six week block with a theoretical and a practical part) and optional courses within the Master's program. Seminars and journal clubs further offer informal ways for students to be involved in our institutional scientific exchange. The 30–35 hours of teaching offered each week during the semesters by our scientists go far beyond the 17 hours mandated by university regulations. And this commitment yields benefits that flow both ways. Teaching at the U KN provides a pipeline for students into MPI-AB research and equips our junior scientists with lecturing and supervising experiences. In the last four years, MPI-AB scientists supervised at U KN 29 Bachelor, 24 Master's, and 10 Doctoral Students, often in cooperation with junior scientists.

We also regularly offer courses, summer schools, and conferences at the Institute for an international audience. The two-week science school AniMove began in 2013 at the previous MPIO in Radolfzell and has since been established as a regular course taking place at different locations. AniMove is a non-profit training initiative run by volunteers of various organisations co-headed by scientists from our MPI-AB.

## International Max Planck Research School for Organismal Biology

### 12 YEARS OF SUCCESSFUL DOCTORAL TRAINING

For the most part, all our Doctoral Students are members of our graduate program, the IMPRS-OB. The IMPRS-OB is a close cooperation between the MPIO in Seewiesen, the MPI-AB, and the Department of Biology at the U KN. It aims to provide first-class training and education in the fields of animal behavior, ecology, evolution, physiology, and neurobiology, for outstanding Doctoral Students from around the world in a stimulating research environment. Founded in 2009, it was successfully evaluated in 2015 and prolonged for a second term ending in February, 2022. The joint IMPRS-OB will discontinue after the second term following the separation of the MPI-AB from the MPIO. Together with U KN, the MPI-AB already applied for a new IMPRS for Quantitative Behavior, Ecology and Evolution from lab to field (IMPRS-QBEE) to guarantee a smooth transition of our Doctoral program.

The IMPRS-OB fosters active participation of Doctoral Students and faculty members in all aspects of IMPRS-OB pursuits. Elected student representatives and faculty members are part of the IMPRS board and so directly involved in the governance and development of the school. The official regulations and the Doctoral Supervision Agreement of the IMPRS-OB stipulate the rights and responsibilities of all parties involved. The IMPRS-OB offers a comprehensive training program in the scientific field, including international events with high-ranking guest speakers, as well as in professional skills to furnish the future careers of our Doctoral Students. Talks by invited speakers during our annual IMPRS symposium, student retreats, public outreach activities, and conferences complement the custom curriculum. All activities are continuously evaluated by the Doctoral Students and tailored to their needs.

### FINANCIAL AND ADVISORY SUPPORT OF DOCTORAL STUDENTS

MPI-AB Doctoral Students are granted a Max Planck support contract for a period of at least three years, with the option for an additional one-year extension. Hence, funding is generally provided by the supervisor until the dissertation defense. For Doctoral Students that come with their own scholarship, the IMPRS-OB requests that the supervisor complements their funding to achieve the same income level as other Doctoral Students, as stipulated by the MPG and, as far as permitted by the funding agencies. An additional safeguard for securing funding is the option to apply for an IMPRS bridge funding for a maximum of six months to cover end phases. Additionally, the IMPRS funds wrap-up Postdoc grants, for up to six months directly after the doctoral thesis, to enable the awardee to finalize their research project and expand their professional and scientific profile before proceeding to the next step. Further financial support of roughly € 1,500 per Doctoral Student is provided by IMPRS-OB for external conference participation and travel.

*IMPRS Alumni Event*

All Doctoral Students within the IMPRS-OB are supported by a personal Thesis Advisory Committee (TAC) for the duration of their studies. The TAC consists of the direct supervisor and at least two other well-established scientists. To ensure objectivity as well as interdisciplinarity, the external members would preferably not have an affiliation or dependence to the candidate's lab and ideally one would be from an institute other than the direct supervisor's institute. Meetings with the TAC take place at least once a year. Responsibilities of the TAC are to monitor research progress; to advise on all aspects of the research project; to address any obstacles and discuss suitable solutions; and to provide support in career planning and networking. In addition, the administration of the MPI-AB and the IMPRS coordinator support all Doctoral Students in day-to-day matters throughout their time with us.

### DOCTORAL STUDENTS AND ALUMNI OF THE IMPRS-OB

Currently, the IMPRS-OB comprises 94 active Doctoral Students: slightly more female than male (59:41%) and the majority from foreign countries (73:27%). Of all Doctoral Students within the IMPRS-OB, 37 are employed and supervised by faculty members at the MPI-AB, and the remaining are at one of the partner institutions in Seewiesen or at the University of Konstanz. In the 2017–2021 reporting period, 43 IMPRS-OB Doctoral Students successfully graduated, 10 of which were from the MPI-AB. The majority of the IMPRS alumni stayed in academia, generally continuing with a Postdoc position, but several moved to a private sector or to an NGO and successfully continued their career outside academia. Our alumni generally stay in contact with the IMPRS-OB and the Institute, and actively participate in further events such as serving as panel members for wrap-up applications, presenting their experiences in career days offered for our junior scientists, or being a point of contact for our active Doctoral Students.

Our IMPRS-OB alumni are well established in academia or related fields. For example, Davide Dominoni holds a lecturer position and leads the City Clocks Group at the University of Glasgow; Adam Fudickar heads the lab of Migration Mechanisms at Indiana University; Catarina Miranda holds a visitor professorship at the Federal University of Pará in Brasil; and Nawang Norbu led a MP Partner Group and is currently the Director of the School for Field Studies (SFS) in Bhutan.

### NOTABLE FEATURES OF THE IMPRS-OB INCLUDE:

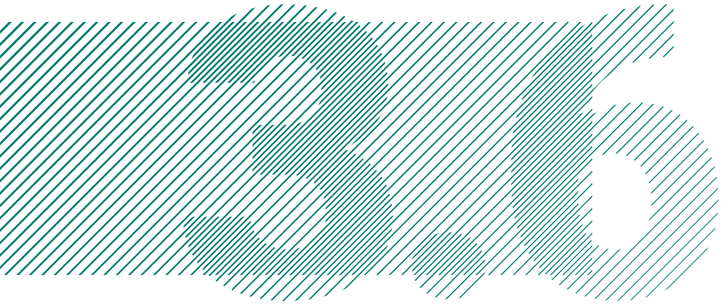
+ Students of the IMPRS-OB receive more than training; they play a leading role in directing their degree. Students direct decisions regarding curriculum, professional development courses, budget, grants, and the annual symposium of the doctoral program.

+ Since its beginning, the IMPRS-OB has supported a diverse and international student composition with currently 73% non-German Doctoral Students coming from 30 countries.

+ The high quality of IMPRS-OB research and training is evidenced by our Doctoral Students publishing nearly 100 papers during the last four years, representing more than 20% of all publications of the MPI-AB.

## Support of Postdoctoral researchers and Group Leaders

As a complement to the doctoral program, we support our Postdoctoral researchers and Group Leaders in their research activities and career planning. Our researchers have access to the academic development programs from U KN as well as MPG. In the last years, the MPG significantly extended its support offers for all career levels, including training opportunities; coaching and mentoring; as well as career planning and perspectives. Following the founding of the Institute, the Directors encouraged the organization and institutionalized support of the Postdoctoral researchers. Elected representatives of our Postdoctoral researchers are now members of the MPG-wide PostdocNet and represent their peers within the Institute. Together with the Science Coordination unit, further institutional measures have been implemented to improve exchange within the Institute (e.g., through new seminar series focusing on the research of our Postdocs); support career development (e.g., with individual coaching and grant writing support); and empower our Group Leaders (e.g., by introducing the official MPG status of Group Leaders).



# EQUAL OPPORTUNITIES

Talent, creativity, and passion—those are the qualities the Max Planck Society relies on. Our Max Planck Institute follows suit, promoting the development of the individual abilities and professional profile of all employees irrespective of gender, nationality, religion, disabilities, age, cultural background, or sexual identity. We take into account the needs of our employees in our working culture and support them not only in their professional development but also with private and family issues. The Welcome Office usually is the first contact point supporting our researchers and visiting scientists in all non-academic matters before, during, and at the end of their stay. Together with the Gender Equality Officers (GEO), they promote measures to facilitate the compatibility of work and family life. For personal or professional concerns, the members of the Works Council and the Ombudspersons treat all matters with discretion and are independent of the Institute management.

## Welcome Office

MPI-AB has become a truly international institute, with more than half of its members having moved from abroad to live and work in Konstanz and Radolfzell (Figure III.13). The Welcome Office was created in 2019 to support these members with the transition to life in Germany, and to cement our reputation internationally as a world-class research environment. The Welcome Office provides assistance at every stage of the process, from applying for a visa and residence permit; to accompanying researchers to appointments with local authorities; to de-registration at the end of the stay. This assistance extends beyond the realm of work. The Welcome Office helps researchers to find accommodation; open bank accounts; place children in schools and daycares; navigate insurance and tax issues; and find foreign-language medical support. In addition to the individual support, the Welcome Office has started to offer joint events on Institute- and country-specific topics enabling social connections and exchange.

### NOTABLE ACTIVITIES BY THE NEWLY ESTABLISHED WELCOME OFFICE INCLUDE:

+ The Institute funded a dedicated position of Welcome Officer to provide centralized support for on- and offboarding of researchers and visiting scientists. Formerly, this was covered by the assistants in the separate Departments.

+ Support has been provided for nearly 100 researchers and visiting scientists in non-academic matters since 2019.

+ Critical support was provided during the COVID-19 situation, including organizing quarantine and testing for scientists upon arrival or departure.

## Gender Equality

MPI-AB has made continual progress to achieving gender equality in the Institute. The percentage of female scientists at the Institute increased in 2017–2021 across all scientific levels, from Doctoral Students to Directors (page 168). The MPI-AB is supported by a dedicated gender equality team, led by a Gender Equality Officer (GEO), who offers assistance to employees and drives progress in Institute-wide efforts towards equal opportunities goals. GEOs are elected in every Max Planck Institute and not bound by instruction in the execution of their duties. At the MPI-AB, the GEO-led team recognizes the early career stage as paramount to achieving equal opportunity at the Institute. And while there is an emphasis on female scientists, who are still heavily underrepresented at higher career levels in science, all genders are included in its focus. Furthermore, the team members recognize that compatibility of work and family life is a key factor for long-term professional success, and so pursue measures to foster that balance. Taking a holistic approach, their initiatives cut across the Institute's other services such as the IMPRS program, the Welcome Office, the Work's Council, and Science Coordination.

### NOTABLE SUCCESSES IN GENDER EQUALITY INITIATIVES INCLUDE:

+ Shortly after the Institute's creation, the GEO team shepherded the first institutional Equal Opportunities Plan (EOP), which was approved in 2019 and updated in 2021. The EOP defines the following five primary fields of action: i) early career support; ii) work life balance and family friendly working conditions; iii) gender and diversity awareness; iv) equal opportunities in selection processes; and v) ensuring a safe and inclusive working environment.

+ The new GEO team, elected in December 2020, include representatives from both the scientific as well as the non-scientific members of the Institute and from different locations and Departments.

## Works Council and Ombudsperson

The MPI-AB staff are represented by the Institute's Works Council, which is elected by the Institute's employees for a period of four years. Having a Works Council is formally mandatory and its rights and responsibilities are defined in the federal Works Council Constitution Act. The Works Council must be consulted about specific issues, such as hiring, and has the right to make proposals to management. In addition, the Works Council is a contact point for anyone who has personal and/or professional concerns and offers support in case of conflicts or problems. For conflicts that involve issues of good scientific practice, the Institute has two ombudspersons who are elected from the academic and academic-technical staff members of the Institute, and in performing their tasks are independent of the Institute management and of superiors and colleagues.

In its mission statement, the MPI-AB committed itself to foster a supportive and inclusive work environment that promotes intellectual exchange and productive collaboration. Initiated by a diversity group at the Institute, the Directors together with the Works Council decided to designate a member of the Works Council as contact person for all issues related to Diversity, Equity, and Inclusion, who will work closely with the GEO in implementing specific fields of action, objectives and measures following the Institute's mission.

# PUBLIC ENGAGEMENT

Public engagement is built into the Institute's DNA. In 1901, our ancestor institution, the world's first ornithological station in Rossitten, began working with volunteer bird ringers. This tradition of nurturing people's inborn fascination with animals in the natural world has continued to this very day. Today this ambition finds its physical expression in our center for communication and exchange, MaxCine, which draws school students out of the confines of the classroom and into the cross section of science, art, and education. Meanwhile our cherished tradition of volunteer bird ringing has been ushered into the digital age with a range of citizen science apps that empower people with a smartphone to take part in research from anywhere in the world.

## MaxCine – a center for communication and exchange

MaxCine is a place in which scientists join forces with school children and members of the public in a mutual mission to explore the vast world of animal behavior. Set between a moated castle and wildflower meadows at the Institute in Radolfzell, MaxCine comprises an interactive workshop space and, separately, the immersive media installation known as The Hennhouse. Part classroom, part laboratory, part studio, it nurtures active, creative, and boundless learning under the motto "Out of school, into science." While visitors experience the everyday life of the Institute's research family, they in turn inspire MPI-AB researchers with open-minded ideas. The MaxCine team works with Institute scientists on a range of public offerings including workshops, field trips, and a public lecture series. They develop communication techniques, both analog and digital, to translate complex interdisciplinary topics. Topics include languages; knowledge of the planet; animal behavior; ethics and sustainability; artificial intelligence; philosophy and art; biological intelligence and intuition; culture and traditions.

### TWO HIGHLIGHT PROJECTS FROM THE MAXCINE PROGRAM WERE:

+ "Earth Guardian 2.0" gave school children the chance to meet the German ISS commander Alexander Gerst in 2019. School classes from all over Germany competed by developing ICARUS-projects to take part, and over 300 children participated in this event (Figure III.9).

+ Since 2017, school children have accompanied scientists into the field, being part of hands-on research projects following tracked white storks on their migration from Germany to Spain, or helping to release and follow ICARUS-tagged blackbirds in Poland or France (Figure III.10).



*Figure III.9 (left) – MaxCine flyer announcing the live-call of the ICARUS-ambassadors and 300 school kids to the ISS.*

*Figure III.10 (right) – MaxCine camps for youngsters: flyer announcing the scientific pilot-project "Blackbirds without borders".*

## Citizen science and volunteers

The MPI-AB was an early adopter of the citizen science movement. Our ancestor Institutes—the Vogelwarte Rossitten, founded 1901, and the Vogelwarte Radolfzell, founded 1946—were actively crowdsourcing volunteers from the local community to help with the labor-intensive bird-ringing studies that ran out of the ornithological stations. This tradition continues today with the MPI-AB Center for Animal Marking (page 82), which works with over 350 volunteers in southern Germany and Berlin. It also includes Hans-Günther Bauer, a research scientist in the Migration Department, who coordinates a large number of volunteer ornithologists to conduct regular censuses of breeding birds around Lake Constance but also across Europe. True to the higher ideals of citizen science, these long-term public partnerships have given rise to mutual benefits: advancement of research on the one hand, and on the other, a fostering of scientific agency in members of the community, some of whom have become experts in a specific bird or population after decades of involvement in the projects.

The advent of smartphones moved the Institute's legacy of citizen science into the digital age. Our most ambitious and far reaching app, "Animal Tracker", draws movement data of tracked animals out of Movebank and shares it with the global public on a user-friendly interface. Users can follow tracked animals wherever these happen to be in the world. In turn, users contribute to research by posting observations and photos of tagged animals that they encounter. Currently running on about 200,000 smartphones worldwide, the app has recently added a function allowing scientists to interact directly with users via push notifications. Scientists might, for example, request photos of a specific place or help with retrieving tags from dead animals. The MPI-AB benefits directly from this user interaction, which for example boosts data on white storks, the most numerous species in the app, and one of our main study species (page 88). Further digitally-based citizen science projects from MPI-AB include: i) the "BigCity-Birds" app developed by MPRG leader Lucy Aplin and Australian colleagues to receive occurrence and behavior observations of cockatoos across Sydney (page 109); ii) the "Cat Tracker" app developed by the Migration Department to determine when house cats are hunting outdoors; or iii) the Animal Snapshot project, also from the Migration Department, which deploys camera traps for long-term monitoring of global animal populations.

### CITIZEN SCIENCE HIGHLIGHTS INCLUDE:

+ The second European Breeding Bird Atlas, published in 2020 and co-edited by Bauer, is one of the largest biodiversity citizen scientist projects of all time.

+ Through the publicly available "AnimalTracker" app, users can follow 7,500 animals of 200 species in near-real time on their local movements and global migrations.

# International, national, and regional media

We take pride in our Institute's heritage of cultivating people's understanding and appreciation of birds of the region. To continue our legacy of impact in the wider community, we actively work with the press to promote the public understanding of our science. This has resulted in increasing coverage of MPI-AB research in international, national, and regional media. An analysis of MPI-AB mentions in online news media captured 1,500 articles in 2020 and 1,800 articles midway through 2021. Much of this media attention is focused on the findings of scientific publications, which can be seen in the paper's Altmetric score. The Altmetric score represents a weighted count of the amount of attention a research output received. Our 474 peer-reviewed publications published in the reporting period have an accumulated Altmetric score of 27,296 and a mean score per paper of 58. The ten papers that received the most public attention are listed in Table III.4.

*ab.mpg.de/SAB*

*Table III.3*
*Ten Twitter accounts with the most followers.*

| ACCOUNT | # OF FOLLOWERS | NAME |
|---|---|---|
| @icouzin | 11,300 | Iain Couzin |
| @animaltracking | 5,400 | Migration Department |
| @LucyMAplin | 3,900 | Lucy Aplin |
| @AniMove | 3,300 | AniMove |
| @CollectiveBehav | 3,000 | Collective Behavior Department |
| @MovebankTeam | 2,000 | Movebank |
| @BlairRCostelloe | 1,900 | Blair Costelloe |
| @DanPapageorgiou | 1,500 | Danai Papageorgiou |
| @livingingroups | 1,500 | Ecology of Animal Societies Department |
| @MegCrofoot | 1,300 | Meg Crofoot |

In addition to covering the results of scientific papers, the media has paid particular attention to our Institute's contributions to global animal telemetry. This includes the launch of ICARUS as well as the potential environmental and societal impacts of animal tracking, such as an early warning system for earthquakes. Examples of recent coverage in English-language media outlets (e.g., *The Guardian, The New York Times, NYT Magazine, Wired, Scientific American*), national German newspapers (e.g., *Frankfurter Allgemeine Zeitung, Süddeutsche Zeitung, Tageszeitung*) as well as TV and radio can be found here: *www.ab.mpg.de/SAB*

In keeping with our heritage, we continue to ensure that our local community reap the benefits of our research. Our ornithological researchers regularly conduct interviews with regional newspapers, radio, and broadcasters to provide expertise on all bird-related topics. In this way, we help tell stories about our science that inform the wider public about new knowledge and foster the fascination of our community.

MEDIA HIGHLIGHTS INCLUDE:

+ At the end of 2020, the Institute employed a communications and media officer to support researchers and the press in promoting MPI-AB science to the public.

+ The media coverage of the Institute is increasing: the number of MPI-AB mentions in online news articles was greater halfway through 2021 (1,800) than the whole of 2020 (1,500).

# Social media

Almost all MPI-AB scientists are active on Twitter and make use of this channel as a platform for personal scientific outreach and public engagement (Table III.3). Twitter is particularly effective for advertising job announcements and for finding volunteers to retrieve bio-loggers from dead animals, generating the fastest and widest-reaching outreach results. The institutional Twitter account @MPI_animalbehav started only in March 2021, but at the time of reporting reached over 600 followers and has been established as an important communication source for the Institute.

*Table III.4 –*
*Ten MPI-AB publications with the highest altmetric score (MPI-AB authors bold).*

| SCORE | AUTHORS | YEAR | TITLE | JOURNAL | DEPT. / GROUP |
|---|---|---|---|---|---|
| 2294 | **Wild** et al. | 2020 | Integrating genetic, environmental, and social networks to reveal transmission pathways of a dolphin foraging innovation | *Current Biology* | Aplin |
| 2271 | **Sampaio** et al. | 2021 | Octopuses punch fishes during collaborative interspecific hunting events | *Ecology* | Couzin |
| 1833 | Rutz et al. | 2020 | COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife | *Nature Ecology & Evolution* | Wikelski |
| 1443 | Smaers et al. | 2021 | The evolution of mammalian brain size | *Science Advances* | Dechmann, Safi |
| 1295 | Kohda et al. | 2019 | If a fish can pass the mark test, what are the implications for consciousness and self-awareness testing in animals? | *PLoS Biology* | Jordan |
| 1002 | Tucker et al. | 2018 | Moving in the Anthropocene: Global reductions in terrestrial mammalian movements | *Science* | Fiedler, Safi, Wikelski |
| 925 | Rahwan et al. | 2019 | Machine behaviour | *Nature* | Couzin |
| 821 | **Davidson** et al. | 2020 | Ecological insights from three decades of animal movement tracking across a changing Arctic | *Science* | Fiedler, Partecke, Safi, Wikelski |
| 781 | Jebb et al. | 2020 | Six reference-quality genomes reveal evolution of bat adaptations | *Nature* | Dechmann |
| 551 | Real et al. | 2020 | The mole genome reveals regulatory rearrangements associated with adaptive intersexuality | *Science* | Dechmann |

# PERSONNEL STRUCTURE

Since the founding of the MPI-AB, the number of staff and guest members has gradually increased more than two-fold to almost 300 members today. More than 70% of these members are part of the Departments and Research Groups—a testament to the Institute's investment in science. The Institute supports a diverse and international community with a special focus on promoting female scientists at all career levels.

## Growth of staff and guests

During the last four years, the number of staff and guest members at the MPI-AB gradually increased from 123 people in 2017 to 285 people in 2021 (Figure III.11), reflecting its establishment as an independent Institute and the addition of the third Department for the Ecology of Animal Societies in 2019. Central Services such as Administration and Technical Services (ATS) and Scientific Services doubled from 2017 to 2021, as our new, independent Institute established its own administration and scientific services. The numbers of people within the Departments and Groups increased even more, by a factor of 2.3, to 163 people in 2021. This illustrates the establishment of the third Department as well as the successful raising of grants (page 170). The number of guest scientists, such as affiliated or visiting scientists from other institutions, also increased by more than three times within the last four years, highlighting the growing position of the MPI-AB within its research areas at a global scale. Interest in cooperation and research stays at our Institute is continuously increasing but currently limited by space availability (page 146).

At the end of the reporting period, more than 70% of the staff members are within the Departments and Research Groups, only 17% belong to Scientific Services, and 13% to the ATS, demonstrating the strong focus on research and science with a rather small but efficient Central Service team. An additional challenge for the Central Services is the current distribution of all Institute members over three locations that requires special effort from the Central Service team regarding communication and on-site support. Junior scientists, combining Doctoral Students and Postdocs, accounted for more than a third of all staff members (Figure III.11).

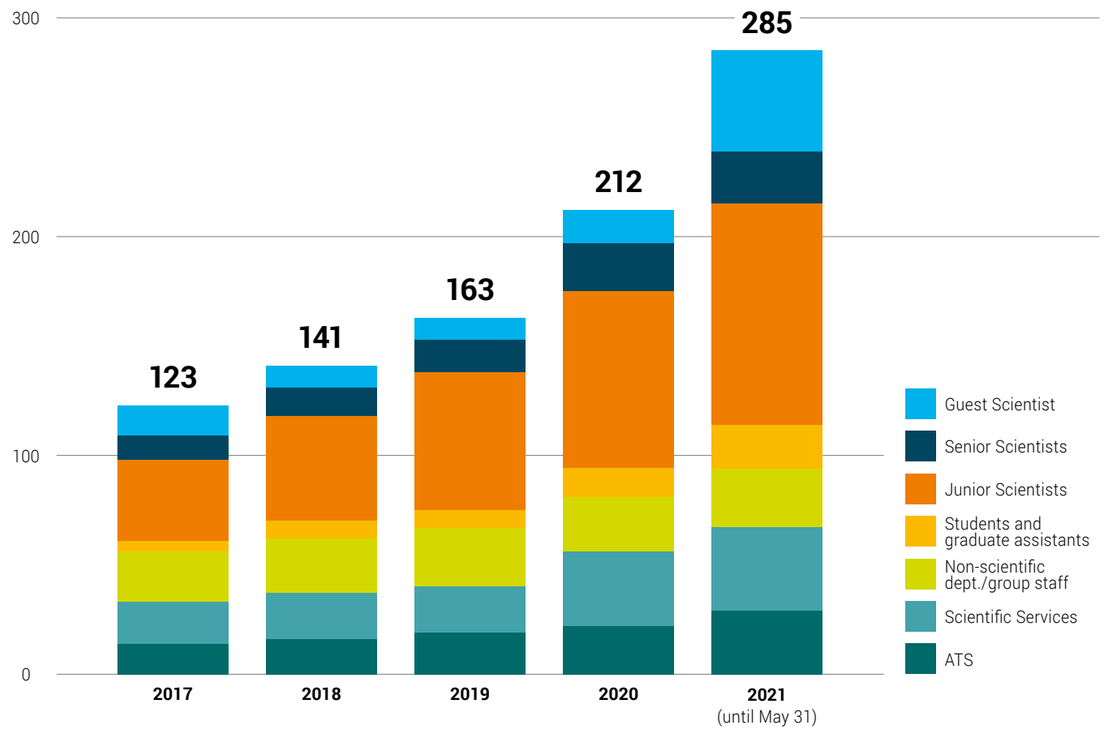



*Figure III.11 – Development of the personnel at the MPI-AB.*

## DEFINITIONS

**+ Central Services**
Administrative and technical as well as scientific services, centrally funded and organized

**+ ATS**
Administration and Technical Services, part of Central Services at the Institute

**+ Scientific Services**
Part of Central Services, including animal holding, communication and outreach, IT, science coordination, Advanced Research Technology (ART) Unit

**+ Departments & Groups**
Comprising all scientists and non-scientific staff of Depts. & Groups

**+ Junior Scientists**
Doctoral Students and Postdocs

**+ Senior Scientists**
Staff Scientists, Group Leaders, and Directors

**+ Guest Scientist**
Visiting researchers and Affiliated Scientists

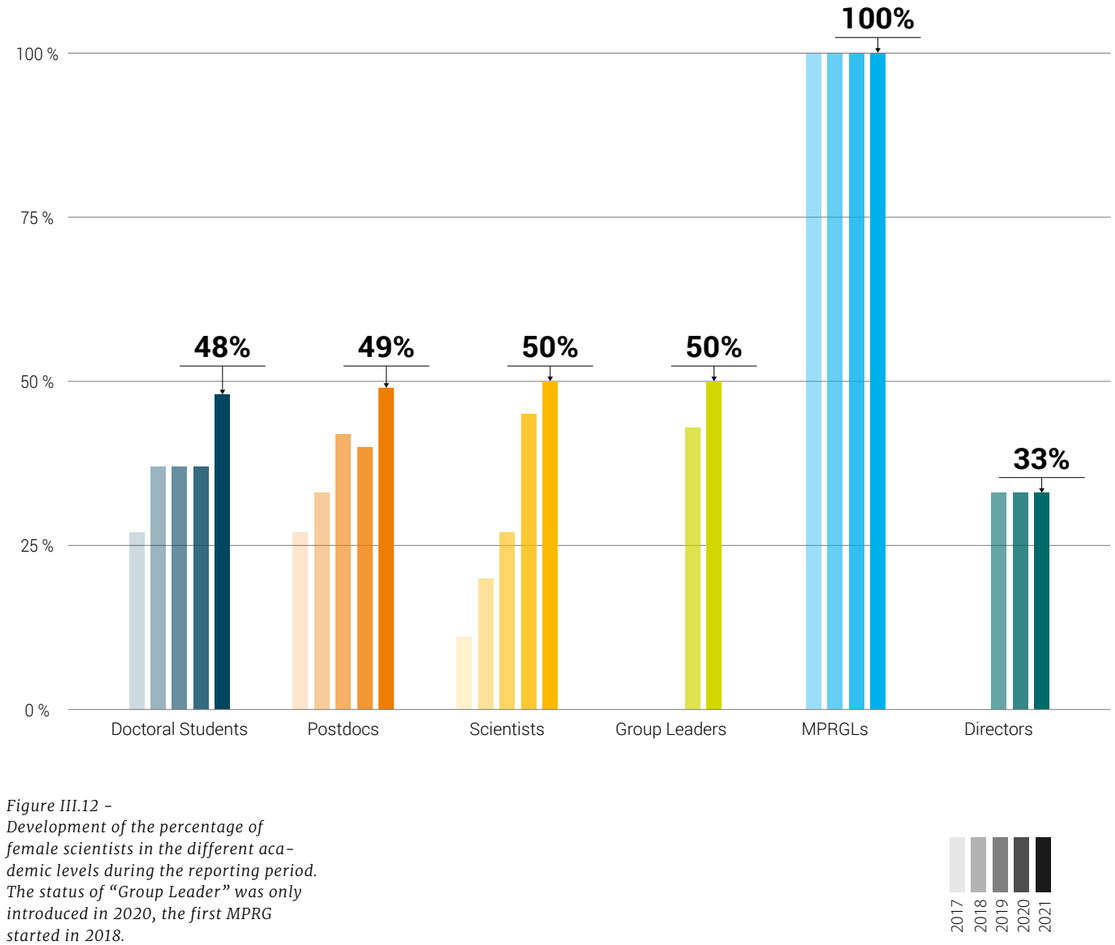



*Figure III.12 – Development of the percentage of female scientists in the different academic levels during the reporting period. The status of "Group Leader" was only introduced in 2020, the first MPRG started in 2018.*

## Gender distribution

In May 2021, over 50% of all staff members at the Institute were women. In ATS 79% are female, 42% in Scientific Services, and 52% in the Departments and Groups. The percentage of female scientists at the Institute increased during the last four years on all scientific levels (Figure III.12), from Doctoral Students (27% in 2017 vs. 47% in 2021) to Directors (0% in 2017 vs. 33% in 2021). Contrary to a general underrepresentation of female scientists at higher levels across academia, the MPI-AB succeeded in increasing the number of female Group Leaders (currently 50%), female MPRGL (100%), and female Directors (currently 33%).

## Nationalities

During the reporting period, the ratio of German vs. non-German staff members continuously decreased from >60% in 2017 to 45 % in 2021. In May 2021, only one-third of the scientific staff (i.e., departmental members, group members, and guest researchers) were German (Figure III.13), and the number of scientists coming from all continents increased during 2017-2021. These numbers highlight the increasing international visibility of MPI-AB as well as the influence that the new, international Directors and Group Leaders have on attracting more international people.

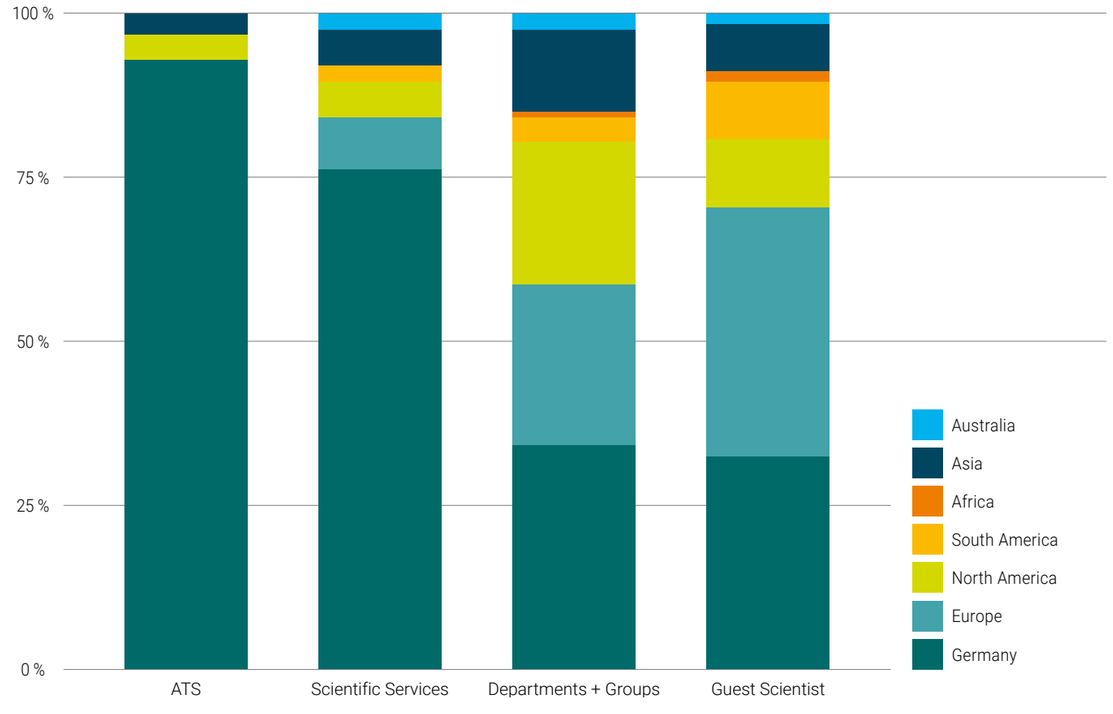



*Figure III.13 – Nationalities in ATS, Scientific Services, Departments & Groups, and Guest Scientists at the end of the reporting period.*

## Terms of employment

The availability of permanent positions differs strongly within the separate areas. Central Services such as ATS and Scientific Services generally offer a high percentage of permanent positions to guarantee continuity and experience, whereas positions in science are usually project- or career-stage related and therefore temporary.

During the reporting period, the number of permanent positions continuously increased; however, compared to the total number of positions, the percentage of permanent positions slightly decreased in all areas. For Central Services, new positions usually get offered with a preliminary 2-year contract before converting it into a permanent contract. We therefore expect several of the currently limited contracts in the Central Services to be converted into permanent positions during the next few years. Within research, the new Director and MPRGLs established their new Groups, hiring primarily young scientists with temporary contracts.

## Age distribution

Staff and guest members at the MPI-AB range in age from 19 (apprentice) to 82 years (Director Emeritus), and are on average 30 years old. There is currently a strong increase of newly employed young Doctoral Students and Postdocs, but also a shift to older and more experienced staff members within ATS, Scientific Services, and Senior Scientists. Senior staff members bring experience and guarantee sustainable knowledge transfer within the Institute but come with higher personnel costs due to their higher salary level.

# FINANCES

Our finances grew considerably during the reporting period. Most expenses are incurred by personnel from the research units. The third-party funding ratio is exceptionally high with the German Aerospace Center being the largest external funding source.

## Financial development

The MPI-AB spent € 56.8 million in the reporting period. Our annual expenses have grown steadily from € 10.6 million in 2017 to € 16.3 million in 2020 (Figure III.14). We expect a further increase for 2021. Core funding through MPG increased in 2019 and 2020 with the establishment of the third Department and the new MPRGs, respectively. Competitive funding through MPG includes the IMPRS, MPRG Aplin, and the Max Planck Yale Center, among others.

The largest share of 71 % (€ 40.3 million) was spent in and for our research units (Departments, Groups, IMPRS). Within the Central Services, a total of € 7.3 million (13 %) was spent on Scientific Services (animal holding, library, IT, science coordination, public outreach, Advanced Research Technology Unit) and € 9.2 million (16 %) was spent on Administration and Technical Services (finance and personnel administration, vehicle fleet, building maintenance, and construction).

More than 50 % of the expenses are personnel costs (Junior Scientists: 17 %; all other employees: 36 %). This does not include stipends paid directly to Junior Scientists by some of the third-party funding sources (e.g., DAAD, AvH, CSC). A share of 6.7 % was spent on instruments (Figure III.15). This category includes all purchases that are either permanently installed and trigger depreciation and/or have an acquisition value of more than € 3,000. The remaining expenses are summarized in the category material expenses. Large individual items include data-loggers and fieldwork, but also subcontracts such as for the development of ICARUS and the programming of Movebank.

Our consistently high third-party funding ratio of 26 % over the entire reporting period (Figure III.14) sets MPI-AB apart from other Max Planck Institutes. The German Aerospace Center (DLR) is our largest third-party funder (41 % of total third-party funding) as a result of the development of ICARUS. A large part of these DLR funds is passed on to subcontractors. Other major third-party funders are the large German and European public funding agencies, but also smaller private foundations and donors (Table III.5). Most third-party funding was administered by the MPI-AB (€ 12.1 million), with € 2.7 million run through the U KN administration.

### KEY FINANCE POINTS IN THE REPORTING PERIOD:

+ More than € 40 million was spent in and for our research units, accounting for 71 % of all expenses.

+ 17 % of all expenses were spent to support our early career researchers.

+ The MPI-AB received nearly € 15 million of third-party funds, accounting for 26 % of our expenses.

+ The entire administration team, which is responsible for the correct receipt and expenditure of funds, their documentation as well as central purchasing, consists of 8 people (6.5 FTE) at the date of reporting.

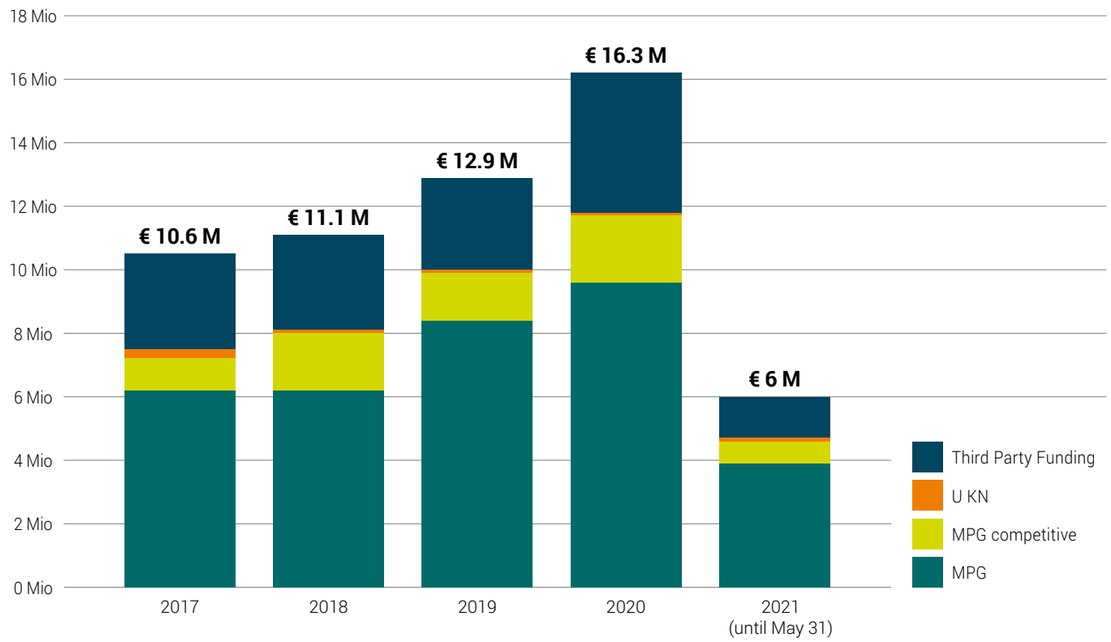



*Figure III.14 – Sources of our annual expenses.*

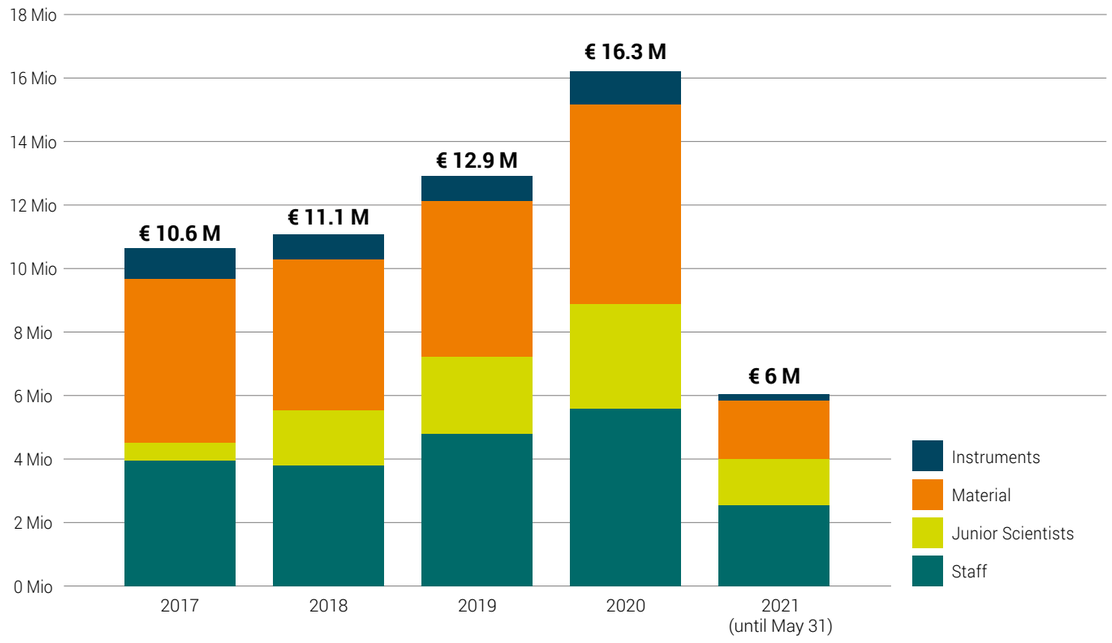



*Figure III.15 – Total expenses per spending category in million €.*

*Table III.5 –*
*Ten largest third-party funding sources.*

| FUNDING SOURCE | TOTAL EXPENSES |
|---|---|
| German Aerospace Center (DLR) | € 6,000,000 |
| German Research Foundation (DFG) | € 1,800,000 |
| Alexander von Humboldt Foundation (AvH) | € 1,600,000 |
| State Ministry of Science of Baden-Württemberg (MWK) | € 1,200,000 |
| European Union (EU) | € 900,000 |
| Knobloch Family Foundation, USA (KFF) | € 800,000 |
| German Private Foundations & Donors | € 700,000 |
| Human Frontier Science Program (HFSP) | € 400,000 |
| National Geographic Society, USA (NGS) | € 300,000 |
| Office of Naval Research, USA (ONR) | € 200,000 |



## SEE YOU NEXT TIME IN KONSTANZ AND RADOLFZELL.

# APPENDIX

## 4.1 Publication list

# PUBLICATION LIST

*Scientific peer-reviewed articles listed by Web of* Science *during the reporting period. MPI-AB members in bold; Doctoral Students underlined*

## A

Abrahms B, **Aikens EO**, Armstrong JB, Deacy WW, Kauffman MJ, Merkle JA. 2021. Emerging perspectives on resource tracking and animal movement ecology. *Trends in Ecology and Evolution* 36: 308-320.

Abrahms B, Seidel DP, Dougherty E, Hazen EL, Bograd SJ, Wilson AM, Mcnutt JW, Costa DP, **Blake S**, Brashares JS, Getz WM. 2017. Suite of simple metrics reveals common movement syndromes across vertebrate taxa. *Movement Ecology* 5: 12.

**Alarcon-Nieto G**, **Graving JM**, **Klarevas-Irby JA**, **Maldonado-Chaparro AA**, **Mueller I**, **Farine DR**. 2018. An automated barcode tracking system for behavioural studies in birds. *Methods in Ecology and Evolution* 9: 1536-1547.

Amornbunchornvej C, Brugere I, **Strandburg-Peshkin A**, **Farine DR**, **Crofoot MC**, Berger-Wolf TY. 2018. Coordination event detection and initiator identification in time series data. *ACM Transactions on Knowledge Discovery from Data* 12: 53.

Apfelbeck B, Haussmann MF, Boner W, Flinks H, Griffiths K, Carlos Illera JC, **Mortega KG**, Sisson Z, Smiddy P, Helm B. 2019. Divergent patterns of telomere shortening in tropical compared to temperate stonechats. *Ecology and Evolution* 9: 511-521.

Apfelbeck B, Helm B, Illera JC, **Mortega KG**, Smiddy P, Evans NP. 2017. Baseline and stress-induced levels of corticosterone in male and female Afrotropical and European temperate stonechats during breeding. *BMC Evolutionary Biology* 17: 114.

Apfelbeck B, **Mortega KG**, Flinks H, Carlos Illera JC, Helm B. 2017. Testosterone, territorial response, and song in seasonally breeding tropical and temperate stonechats. *BMC Evolutionary Biology* 17: 101.

**Aplin LM**. 2019. Culture and cultural evolution in birds: A review of the evidence. *Animal Behaviour* 147: 179-187.

**Aplin LM**, Major RE, Davis A, Martin JM. 2020. A citizen science approach reveals long-term social network structure in an urban parrot, *Cacatua galerita*. *Journal of Animal Ecology* 90: 222-232.

Armansin NC, Stow AJ, **Cantor M**, Leu ST, **Klarevas-Irby JA**, Chariton AA, **Farine DR**. 2020. Social barriers in ecological landscapes: The social

resistance hypothesis. *Trends in Ecology and Evolution* 35: 137-148.

Arrondo E, Garcia-Alfonso M, Blas J, Cortes-Avizanda A, De La Riva M, Devault TL, **Fiedler W**, **Flack A**, Jimenez J, Lambertucci SA, Margalida A, Oliva-Vidal P, Phipps L, Sanchez-Zapata JA, **Wikelski M**, Donazar JA. 2021. Use of avian GPS tracking to mitigate human fatalities from bird strikes caused by large soaring birds. *Journal of Applied Ecology* 58: 1411-1420.

Aspillaga E, **Safi K**, Hereu B, Bartumeus F. 2019. Modelling the three dimensional space use of aquatic animals combining topography and Eulerian telemetry data. *Methods in Ecology and Evolution* 10: 1551-1557.

## B

Baldan D, **Curk T**, Hinde CA, Lessells CM. 2019. Alternation of nest visits varies with experimentally manipulated workload in brood-provisioning great tits. *Animal Behaviour* 156: 139-146.

Baldwin JW, **Dechmann DKN**, Thies W, Whitehead SR. 2020. Defensive fruit metabolites obstruct seed dispersal by altering bat behavior and physiology at multiple temporal scales. *Ecology* 101: e02937.

Balsby TJS, Eldermire ERB, **Schnell JK**, Poesel A, Walsh RE, Bradbury JW. 2017. Function of vocalization length and warble repertoire size in orange-fronted conures. *Animal Behaviour* 134: 301-310.

**Barrett BJ**, Zepeda E, Pollack L, Munson A, Sih A. 2019. Counter-culture: Does social learning help or hinder adaptive response to human-induced rapid environmental change? *Frontiers in Ecology and Evolution* 7: 183.

**Barrett BJ**, Monteza-Moreno CM, Dogandzic T, Zwyns N, Ibanez A, **Crofoot MC**. 2018. Habitual stone-tool-aided extractive foraging in white-faced capuchins, *Cebus capucinus*. *Royal Society Open Science* 5: 181002.

**Bastien R**, **Guayasamin O**, Douady S, Moulia B. 2018. Coupled ultradian growth and curvature oscillations during gravitropic movement in disturbed wheat coleoptiles. *PLoS ONE* 13: e0194893.

**Bastien R**, Porat A, Meroz Y. 2019. Towards a framework for collective behavior in growth-driven systems, based on plant-inspired allotropic pairwise interactions. *Bioinspiration and Biomimetics* 14: 055004.

**Bastien R**, Romanczuk P. 2020. A model of collective behavior based purely on vision. *Science Advances* 6: eaay0792.

Bastille-Rousseau G, Douglas-Hamilton I, **Blake S**, Northrup JM, Wittemyer G. 2018. Applying network theory to animal movements to identify properties of landscape space use. *Ecological Applications* 28: 854-864.

Bastille-Rousseau G, Gibbs JP, Campbell K, Yackulic CB, **Blake S**. 2017. Ecosystem implications of conserving endemic versus eradicating introduced large herbivores in the Galapagos Archipelago. *Biological Conservation* 209: 1-10.

Bastille-Rousseau G, Gibbs JP, Yackulic CB, Frair JL, Cabrera F, Rousseau LP, **Wikelski M**, Kuemmeth F, **Blake S**. 2017. Animal movement in the absence of predation: Environmental drivers of movement strategies in a partial migration system. *Oikos* 126: 1004-1019.

Bastille-Rousseau G, Yackulic CB, Gibbs JP, Frair JL, Cabrera F, **Blake S**. 2019. Migration triggers in a large herbivore: Galápagos giant tortoises navigating resource gradients on volcanoes. *Ecology* 100: e02658.

Baugh AT, **Davidson SC**, Hau M, Van Oers K. 2017. Temporal dynamics of the HPA axis linked to exploratory behavior in a wild European songbird (*Parus major*). *General and Comparative Endocrinology* 250: 104-112.

Baugh AT, Witonsky KR, **Davidson SC**, Hyder L, Hau M, Van Oers K. 2017. Novelty induces behavioural and glucocorticoid responses in a songbird artificially selected for divergent personalities. *Animal Behaviour* 130: 221-231.

Bautista C, Naves J, Revilla E, Fernandez N, Albrecht J, **Scharf AK**, Rigg R, Karamanlidis AA, Jerina K, Huber D, Palazon S, Kont R, Ciucci P, Groff C, Dutsov A, Seijas J, Quenette PI, Olszanska A, Shkvyria M, Adamec M, Ozolins J, Jonozovic M, Selva N. 2017. Patterns and correlates of claims for brown bear damage on a continental scale. *Journal of Applied Ecology* 54: 282-292.

Bayerl H, **Kraus RHS**, Nowak C, Foerster DW, Fickel J, Kuehn R. 2018. Fast and cost-effective single nucleotide polymorphism (SNP) detection in the absence of a reference genome using semi-deep next generation random amplicon sequencing (RAMseq). *Molecular Ecology Resources* 18: 107-117.

Becciu P, **Menz MHM**, Aurbach A, Cabrera-Cruz SA, Wainwright CE, **Scacco M**, Ciach M, Pettersson LB, Maggini I, Arroyo GM, Buler JJ, Reynolds DR, Sapir N. 2019. Environmental effects on flying migrants revealed by radar. *Ecography* 42: 942-955.

Becciu P, Rotics S, Horvitz N, Kaatz M, **Fiedler W**, Zurell D, **Flack A**, Jeltsch F, **Wikelski M**, Nathan R, Sapir N. 2020. Causes and consequences of facultative sea crossing in a soaring migrant. *Functional Ecology* 34: 840-852.

Beck KB, **Farine DR**, Kempenaers B. 2020. Winter associations predict social and extra-pair mating patterns in a wild songbird. *Proceedings of the Royal Society B* 287: 20192606.

Beck KB, **Farine DR**, Kempenaers B. 2021. Social network position predicts male mating success in a small passerine. *Behavioral Ecology*: arab034.

Beck KB, **Loretto MC**, Bugnyar T. 2020. Effects of site fidelity, group size and age on food-caching behaviour of common ravens, *Corvus corax*. *Animal Behaviour* 164: 51-64.

Beekman M, **Jordan LA**. 2017. Does the field of animal personality provide any new insights for behavioral ecology? *Behavioral Ecology* 28: 617-623.

Benitez-Capistros F, Couenberg P, Nieto A, Cabrera F, **Blake S**. 2019. Identifying shared strategies and solutions to the human–giant tortoise interactions in Santa Cruz, Galapagos: A nominal group technique application. *Sustainability* 11: 2937.

Berdahl AM, Kao AB, **Flack A**, Westley PAH, Codling EA, Couzin ID, Dell AI, Biro D. 2018. Collective animal navigation and migratory culture: From theoretical models to empirical evidence. *Philosophical Transactions of the Royal Society B* 373: 20170009.

Bergler C, Schmitt M, Maier A, **Smeele S**, Barth V, Noth E. 2020. ORCA-CLEAN: A deep denoising toolkit for killer whale communication. *Interspeach 2020*: 1136-1140.

Berteaux D, Thierry AM, Alisauskas R, Angerbjorn A, Buchel E, Doronina L, Ehrich D, Eide NE, Erlandsson R, Flagstad O, Fuglei E, Gilg O, Goltsman M, Henttonen H, Ims RA, Killengreen ST, Kondratyev A, Kruchenkova E, Kruckenberg H, Kulikova O, Landa A, Lang J, Menyushina I, Mikhnevich J, Niemimaa J, Noren K, Ollila T, Ovsyanikov N, Pokrovskaya L, **Pokrovsky I**, Rodnikova A, Roth JD, Sabard B, Samelius G, Schmidt NM, Sittler B, Sokolov AA, Sokolova NA, Stickney A, Unnsteinsdottir ER, White PA. 2017. Harmonizing circumpolar monitoring of Arctic fox: Benefits, opportunities, challenges and recommendations. *Polar Research* 36: 2.

Blas J, Salas R, **Flack A**, Torres-Medina F, Sergio F, **Wikelski M**, **Fiedler W**. 2020. Overland and oversea migration of white storks through the water barriers of the straits of Gibraltar. *Scientific Reports* 10: 20760.
Boelman NT, Liston GE, Gurarie E, Meddens AJH, Mahoney PJ, Kirchner PB, Bohrer G, Brinkman TJ, Cosgrove CL, Eitel JUH, Hebblewhite M, Kimball JS, **Lapoint S**, Nolin AW, Pedersen SH, Prugh LR, Reinking AK, Vierling LA. 2019. Integrating snow science and wildlife ecology in Arctic-boreal North America. *Environmental Research Letters* 14: 010401.
Boiko D, **Wikelski M**. 2019. Moulting sites of Latvian Whooper Swan *Cygnus cygnus cygnets* fitted with GPS-GSM transmitters. *Wildfowl* 5: 229-241.

Bond ML, Koenig B, Lee DE, Ozgu A, **Farine DR**. 2020. Proximity to humans affects local social structure in a giraffe metapopulation. *Journal of Animal Ecology* 90: 212-221.

Bond ML, Koenig B, Ozgul A, **Farine DR**, Lee DE. 2021. Socially defined subpopulations reveal demographic variation in a giraffe metapopulation. *The Journal of Wildlife Management* 85: 920-931.

Bond ML, Lee DE, **Farine DR**, Ozgul A, Konig B. 2021. Sociability increases survival of adult female giraffes. *Proceedings of the Royal Society B* 288: 20202770.

Boogert NJ, Lachlan RF, Spencer KA, Templeton CN, **Farine DR**. 2018. Stress hormones, social associations and song learning in zebra finches. *Philosophical Transactions of the Royal Society B* 373: 20170290.

**Bose APH**, Borowiec BG, Scott GR, Balshine S. 2019. Nesting on high: Reproductive and physiological consequences of breeding across an intertidal gradient. *Evolutionary Ecology* 33: 21-36.

**Bose APH**, Houpt N, Rawlins M, Miller JS, Juanes F, Balshine S. 2020. Indirect cue of paternity uncertainty does not affect nest site selection or parental care in a Pacific toadfish. *Behavioral Ecology and Sociobiology* 74: 24.

**Bose APH**, Lau MJ, Cogliati KM, Neff B, Balshine S. 2019. Cannibalism of young is related to low paternity and nest take-overs in an intertidal fish. *Animal Behaviour* 153: 41-48.

**Bose APH**, Windorfer JW, Boehm AB, Ronco F, Indermaur A, Salzburger W, **Jordan A**. 2020. Structural manipulations of a shelter resource reveal underlying preference functions in a shell-dwelling cichlid fish. *Proceedings of the Royal Society B* 287: 20200127.

**Bose APH**, Zayonc D, Avrantinis N, Ficzycz N, Fischer-Rush J, Francis FT, Gray S, Manning F, Robb H, Schmidt C, Spice C, Umedaly A, Warden J, Cote IM. 2019. Effects of handling and short-term captivity: A multi-behaviour approach using red sea urchins, *Mesocentrotus franciscanus*. *PeerJ* 7: e6556.

**Bose APH**, Zimmermann H, Sefc KM. 2019. Freshwater hydrozoan blooms alter activity and behaviour of territorial cichlids in Lake Tanganyika. *Royal Society Open Science* 6: 191053.

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