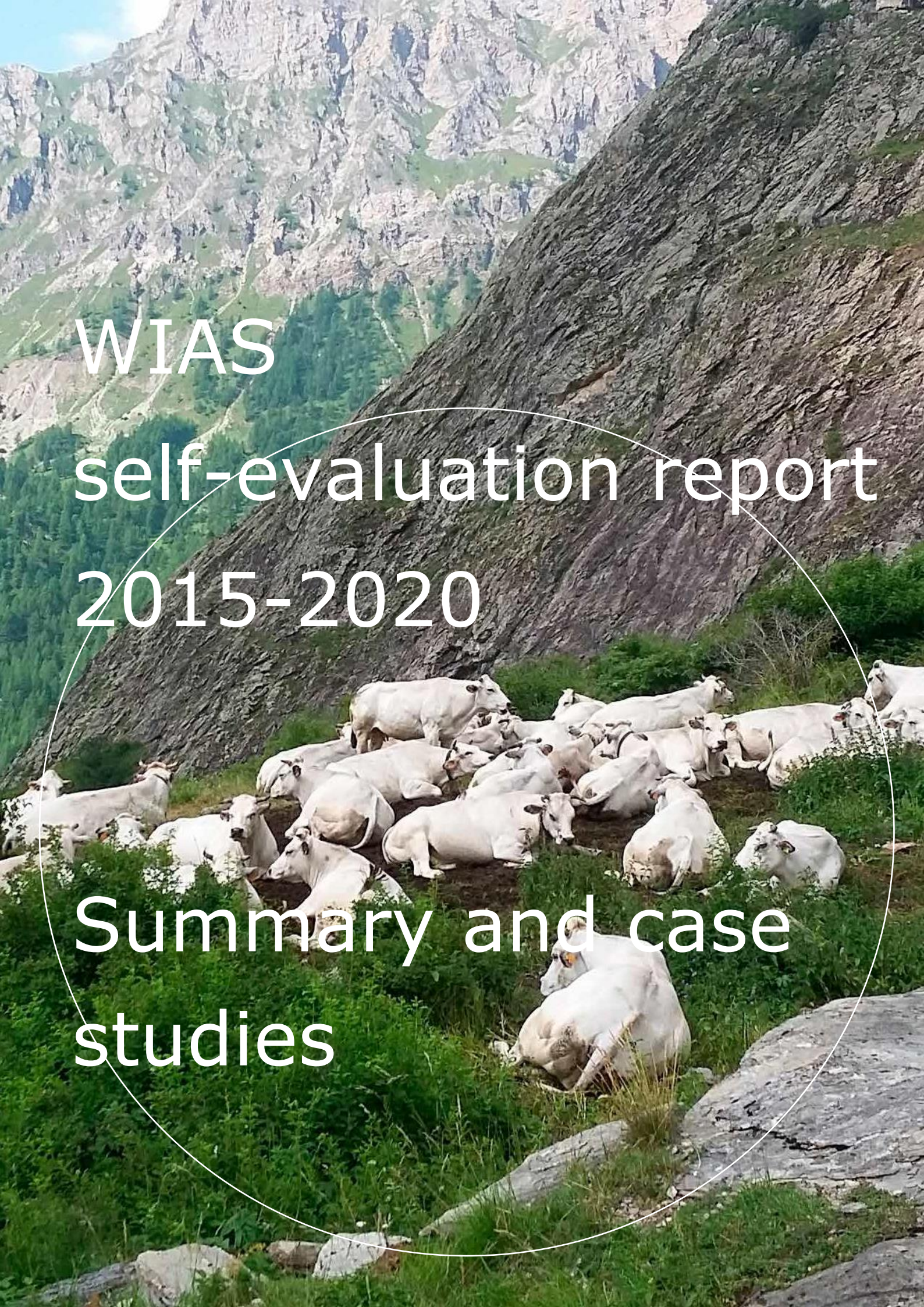

WIAS self-evaluation report 2015-2020

Summary and case studies

Summary Graduate School Wageningen Institute of Animal Sciences

The Graduate School Wageningen Institute of Animal Sciences (WIAS) is the only graduate school in the domain of fundamental and applied animal sciences in the Netherlands. WIAS was established on May 25th, 1993. Its mission is: 'To improve our understanding of animals and their various roles for mankind through fundamental and strategic research and training of early-stage researchers (PhD and postdoc)'. The task of WIAS is to enhance, support and monitor the progress and quality of the PhD candidate education programme and to safeguard and monitor the quality of the research from early-stage researchers in the 13 chair groups of Wageningen University involved in WIAS.

WIAS aims to provide optimal training and support for early-stage researchers to develop themselves as independent animal scientists at the highest international level. Over the past six years, on average ~240 PhD candidates per year were enrolled in WIAS with, on average, 33 PhD candidates graduating each year (25-40). The median time to graduate is 4.5 years, which is what WIAS aims for (four years of research and another 3-6 months for the formal procedure for the approval of the thesis and the defence of the thesis). WIAS has a high graduation rate, with only 10% drop-outs.

WIAS organises between 17-31 courses per year and has further optimised its course programme by introducing several new courses; e.g. "Societal impact" to teach PhD candidates how to contextualise their research within broader societal issues and "The final touch" to support PhD candidates in writing the general introduction and discussion of their thesis.

WIAS research aims to contribute to environmentally sustainable animal production systems, where animal health and welfare are guiding principles. It focuses on the performance of animals in nature and in food production systems and on transforming the latter systems to become more nature-inclusive, climate smart, healthy and circular (terrestrial and aquatic). In order to achieve this, WIAS researchers investigate the biological mechanisms of animal functioning in an evolutionary and ecological context at multiple levels, from molecule to (production) system.

The three WIAS clusters address different aspects of the basic functioning of animals, animal and human health, animal welfare and resilience and the transition of animal production chains towards sustainable food systems. WIAS stimulates collaboration between chair groups and between clusters on key questions requiring interdisciplinary and transdisciplinary approaches. We emphasise the alignment and complementarity between clusters as this is where many new insights and applications are generated by pursuing an integrated approach, with the aim of contributing to the major societal challenges within our domain.

WIAS' research output, measured in academic publications, has increased by 20% during the last six years. The average Field Weighted Citation Impact has been very stable at around 1.54, which means that WIAS research is cited 54% more often than the world average. 20% of the published articles belong to the 10% most cited in their field. The percentage of open access publications drastically increased from 33% to 76%, in line with the policy of Wageningen University and the NWO. Over the last 6 years, 9 Veni, 2 Vidi and 1 Marie Curie IF grants were awarded to WIAS researchers. WIAS researchers are also increasingly visible in the societal debate. They participate in events like FameLab, TED talks, write Blogs and columns and actively communicate their latest findings through social media.

Global food security faces major challenges and needs to be resolved in science-society collaboration, to which WIAS can contribute greatly. We aim to further our international reputation as front runner school in Animal Sciences. We will provide researchers from diverse disciplinary backgrounds, cultures, and genders, a secure home to excel in inter- and trans-disciplinary animal research. WIAS will further improve itself by addressing the weaknesses described in this self-evaluation. In the next six years WIAS will strengthen its education and research programme by seeking opportunities such as introducing blended learning to create flexibility in the WIAS course portfolio, strengthening the connection with the three institutes of Wageningen Research involved in animal sciences to create new opportunities for PhD projects and courses, and strengthening our connection with industry and NGOs by developing a new track for Engineering Degrees.

Summary Integrative Biology

The mission of the Integrative Biology Cluster (IB) is to improve the understanding of how animals develop, function, interact and evolve in different environments. Using a multispecies approach, the IBC focuses on understanding at a fundamental level how environmental factors influence the performance and resilience of individuals, populations and ecosystems, underpinning strategies to address global challenges. To support our mission, we adopt an interdisciplinary approach that spans all levels of biological organisation, from the molecular to ecosystem scales.

The integrative biology cluster aims to:

1) improve the mechanistic and functional understanding of animals, humans and microorganisms in interaction with their biotic and abiotic environments, by applying combined quantitative experimental, data analysis, and modelling approaches.
2) translate elucidated biological mechanisms into solutions to (1) strengthen animal and human health and prevent and cure disease, and (2) provide knowledge to improve biodiversity conservation strategies.
3) develop and maintain a leading position in integrative biology, including research and training of young academics.

The overarching research theme of the IBC is multi-scale integrative biology focused on the performance and resilience of animals, which entails two main interlinked subthemes: (1) health and metabolism and (2) behaviour and ecology. These two subthemes are linked as the health and metabolism of an animal directly influences its behaviour and interactions with the environment, and vice versa. Performance and resilience connect the two subthemes. In the Health and Metabolism subtheme, we aim to improve understanding of mechanisms and processes underlying individual health and performance as well as resilience to infection or stress. We focus on the complex interactions between energy metabolism, mitochondrial function, the immune system and microbiota in intestinal health as well as physiological effects beyond the gut. In the Behaviour and Ecology subtheme, we aim to improve the understanding of the trade-offs underlying animal movement on the following three scales: the biophysical mechanisms and constraints of movement, decision making by individuals, and effects on population level.

A major contribution to society is the training of young scientists. In the IBC, they develop scientific skills and competences that will positively influence their future discoveries. They also learn to develop interdisciplinary scientific interests and tackle difficult problems. These early-stage scientists will be the next generation of key innovators and creators, providing the intellectual capital needed to advance scientific theory and solve the problems of the future.

The fundamental knowledge of mechanisms underlying the resilience and performance of animals, humans and ecosystems contributes to resolving problems related to an increasingly aging and obesogenic human population, to increased pressure on ecosystems and biodiversity and to issues related to intensive food production and the use of animals. This knowledge will help to develop solutions and improve rational decision making. The research will also lead to new research tools and applications.

In the past six years, we have generated high-quality scientific output and obtained a leading international position in several disciplines. We have built two strong sub-themes of high societal relevance. Our fundamental understanding of biological mechanisms has led to innovative applications. We built first-rate infrastructure, with excellent sites for field work and state-of-the-art technology and tools, such as modelling of complex systems, in vivo imaging, animal tracking solutions, functional metabolic testing, microscopy, molecular cell and microbial biology and biochemistry.

In the coming six years, we will continue on our path, aiming to further increase our scientific excellence and impact. Our main opportunities are to integrate research over various levels of organisation (cell – organ – individual – population), to further exploit our multi-species expertise and facilities, to use our expertise to contribute to alternatives and refinements for animal and human experimentation (complex cell systems, mathematical models, and non-invasive in vivo imaging).

Case studie: Gut barrier functions, mucosal immunity and the gut-lung axis in early life and old age

In infants and neonatal animals, we have studied how factors in milk influence gut barrier functions and mucosal immunity and the gut-lung axis as well as the development of the microbiota. We also studied how various milk components nutritionally programme later life metabolic health in preclinical models. We connected this to human whole-body physiology studying circulating lipid profiles and exhaled air upon consumption of infant formulas of different composition6. We have also studied weaning in piglets and how common infections such as invasive Streptococcus suis disease and infectious post-weaning diarrhoea can be reduced. Therefore, we studied how energy metabolism and fasting affects intestinal barrier function of the gut. We have developed tools to assess substrate oxidation and intestinal fermentation non-invasively in mice, which help us to resolve interactions between nutrients and the functioning of the intestine and other organs. In naturally ageing mice, we gained novel insights into the age-associated impairment of the mucus barrier function, revealing microbiota changes and a decline in gut barrier function that may even trigger the low-grade chronic inflammation or "inflammageing" typical of old age. Fast ageing mouse models were used to look at the effects of microbial interventions on lifespan and intestinal functions.

Case study: Effects of microbial metabolites on host physiology

Metabolites produced by resident microbiota impact on host physiology through acting as host signalling molecules and substrates for metabolic reactions. We have studied how different metabolites affect liver and muscle function. As members of the Metagenomics of the Human Intestinal Tract (MetaHIT) Consortium, we showed how the human gut microbiome impacts on the serum metabolome of insulin-resistant non-diabetic individuals and the identification of Prevotella copri and Bacteroides vulgatus as the main species driving the association between biosynthesis of branched chain amino acids and insulin resistance. We also have a strong interest in microbial metabolites of tryptophan that effect the host–microbiota immune tolerance and mucosal homeostasis through activation of the Aryl hydrocarbon receptor (AhR) in different cell types. AhR signalling is required for maintenance of intra-epithelial lymphocytes and innate lymphoid cells in the mucosa which produce IL-22. We showed that the IL-22 pathway is important for ileal homeostasis and resilience to infection. Recently we showed that patients with active coeliac disease exhibited a reduction in AhR ligands in stools and a decreased capacity of the gut microbiota to activate AhR19. We showed that a diet enriched in tryptophan increased AhR ligand production and AhR pathway activation, which reduced immunopathology in a mouse model of coeliac disease. Currently, we are studying the effects of tryptophan in a human trial with a view to testing tryptophan supplementation in coeliac patients.

Case study: Aging and systemic health

We study how risk factors (aging, lifestyle, chronic disease) affect the relation between energy metabolism and function of skeletal muscle and the heart. Important side effects of widely used pharmaceuticals such as statins can impair mitochondrial function, leading to severe skeletal muscle pain. We focus on how muscle function, including innervation, changes with age. We showed that skeletal muscle mitochondrial function is decreased in 75+ year old males and females and that this decrease is stronger in prefrail compared to fit individuals. Moreover, men age differently from women. Using near-infra red spectroscopy, we non-invasively assessed muscle mitochondrial function in humans, showing differences in sedentary vs active males and females. By comparing young and old individuals with similar physical activity levels, we showed that different muscles age differently24. We also showed that oxidative metabolism was the main down regulated process with aging, while matrisome, innervation and inflammation were upregulated. We also study how muscle function relates to metabolic changes in circulating immune cells.

Case study: Infectious diseases and novel vaccination strategies

To improve the health of animals and humans, we study the development of new vaccines, optimisation of vaccine responses and discovery of new antimicrobial drugs or alternatives to antibiotics. Furthermore, we contribute to the culturing of new genera and species of the gut microbiome and identified bacteria which express novel biosynthetic gene clusters producing antibiotics that shape microbial ecosystems in vivo. We also explore probiotic, prebiotic and dietary approaches to enhance immune competence and resistance to infections in animals and humans. To enhance the therapeutic and vaccine effectiveness, we use nanoparticles to stimulate the immune system and immunomodulators to enhance the vaccine-specific immune response. Besides improved vaccination strategies, we employ a similar strategy to mitigate allergic responses in humans and animals. We recently studied what immunological factors contribute to the challenge with an attenuated enterotoxigenic E. coli strain E1392/75-2A (ETEC) that prevents diarrhoea upon a secondary challenge with the same bacteria.

Case study: Movement mechanisms

The physical interactions between an animal and its environment and its intrinsic neuro-mechanical mechanisms are fundamental to the understanding of animal motion and body morphology throughout its life31. To reveal these interactions, we require interdisciplinary approaches that combine experiments with mechanistic modelling. We apply a generic biophysical approach to fish swimming and insect flight. We study the development of swimming performance in larval bony fish, which change their shape and size and thus their interaction with the fluid environment. We developed a unique automated 3D-motion open-source analysis system that quantifies the displacements, rotations, and body shape at a resolution of thousands of frames per second. These motions were used as input for a fluid dynamics solver enabling us to compute the force distribution on the body, and the varying net actuation along the body as a proxy for the neuromechanical output. This showed that the actuation is simple, yet remarkably effective, and strikingly similar throughout larval development, which may facilitate their rapid restructuring of the neuromuscular system during development. Using the inverse dynamics analysis developed for larval fish, we showed how pregnancy affects the fast-start performance in three life-bearing fish species. Using similar biomechanical approaches, we quantified the take-off biomechanics of malaria mosquitoes and showed that their aerodynamic ground effect is negligible and (2) that their push-off forces for blood-fed and non-fed conditions are below the detection limit of humans.

Case study: Movement decisions by individuals within a population

With respect to understanding individual movement decisions within the social and ecological environment, we have shown, for instance, that territorial animals form complex societies consisting of social networks beyond their territorial boundaries with long range signals influencing movement decisions within this network. Using fully automatised radio-tracking systems, we have continuously and simultaneously monitored the small-scale movements of multiple animals, using great tits as model organism. We revealed personality based social network structures and predicted movement patterns of territorial males and females into the neighbourhood, based on male singing behaviour. The series of studies added up to the largest radiotracking project on songbirds worldwide and provided important information on how habitat fragmentation interferes with the social organisation of animal societies. The projects also led to a larger joint project on the role of social networks in animal conservation. These tracking projects are exciting because we can unravel previously unnoticed decisions by animals. This allows us to determine social structures and responses to resource distribution and environmental challenges. With rapid technological developments, these projects also open new paths to future possibilities. To obtain a better understanding of the dynamics of social organisation under changing and challenging environmental conditions, we now apply such analysis of movement decisions and the consequences for habitat choices and conservation, using advanced solar-powered radio-tracking technologies, to a larger set of species, covering a broader diversity of habitats.

Case study: The role of animal movements within the ecosystem in relation to emerging population distributions

Animals play a key role in ecosystem functioning. One of the fundamental questions is what determines the distribution and population density of animal species. Within their range, individual animals move to search for resources and mates and to avoid predators. Nowadays, these search and predator avoidance movements are often constrained by human activities, which could negatively affect behavioural performance and survival. To understand animal performance and adaption to natural and human-dominated conditions, fundamental knowledge is required on the social environment and the ecological conditions in which animals evolve. We show the interactive effects of stressors, i.e. parasites and pesticides, on animal performance by using honeybees as a model species. To better understand the drivers of animal distribution and densities, we studied the movement of ungulates using GPS tags to determine the effects of unfavourable weather conditions, such as heat and drought, and predation risk on habitat choice, showing sub-optimal choices due to these stressors. We invested in the development of new GPS trackers and new analysis techniques. Based on these technological advances and our understanding of prey responses to predators, we convincingly showed that changes in the behaviour of ungulates indicate with high accuracy the presence and location of human intruders (e.g. poachers) in a protected area.

Summary Future Food Systems

The Research Unit Animals in Future Food Systems and Society, comprising the chair groups Adaptation Physiology, Animal Nutrition, Animal Production Systems and Aquaculture and Fisheries, has as vision for "A world where animals are kept in harmony with society's norms and values". Its mission is "to develop knowledge for the transition towards a sustainable role of animals in food systems and society". Such knowledge development applies to the role of animals in food production, but also in ecosystem services, support of livelihood strategies and leisure. This mission is addressed through research along three lines: 1) the role of animals in circular food systems in temperate and tropical regions. Animals in such systems can convert leftover biomass into valuable food. Effects of circularity on the environment, animal welfare and livelihood are investigated and farming systems, value chains and food systems are designed with optimal consideration for animals; 2) Animal health and welfare in future food systems. Understanding the challenges animals encounter at different stages of their lives and investigating and design of interventions that improve long term health and welfare are the major objectives of this research line; 3) Understanding the interactions between biomass characteristics, animal production and food in future food systems. This research line develops new models and approaches that characterise and objectively quantify impacts of changes in biomass composition (for example by biotechnological approaches), animal production characteristics (housing, breeding, health, welfare) on food and on the role of animals in food systems.

The knowledge generated is disseminated in such a manner that it supports the public discourse regarding sustainable food systems, and it contributes to the work of our stakeholders i.e. policy makers, non-governmental organisations, industry, farmers, veterinarians and societies. We publish in open access scientific journals and contribute through guest lectures, presentations at conferences and post-academic courses, using both traditional and social media exposure. On the other hand, we are also involved in the discourse to have "antennae in society", to identify new research questions which we may further develop with those participating in this discourse. The Research Unit has become a leader in developing and implementing the concept of circularity in food systems and is involved in many innovative research projects. A holistic vision of a healthy and circular food system in the Netherlands, written by Prof. de Boer and Dr de Olde, was awarded the prestigious Food System Vision Prize by the Rockefeller Foundation.

Regarding animal welfare and health, approaches have been developed to reduce the burden of chronic stressors and improve resilience during transition periods. The Research Unit was co-initiator of the Centre for Sustainable Stewardship, to discuss societal issues regarding animal production. Studies of the emotional state of animals, on-farm welfare assessments and sensor technology are examples of innovative approaches in our research on animal health and welfare. Biotechnology to upgrade the quality of low value biomass with industrial potential has been developed by the Research Unit. In addition, better insight into livestock methane emissions, N-utilisation by dairy cattle and influence of diets on pig behaviour have been gained. These were important for policy making with regards to environmental impacts and farm animal welfare in the Netherlands. Research and teaching are closely connected in the Research Unit and knowledge generated finds its way into courses at Bachelor, Master, PhD and post-academic level. Research and teaching is carried out by a staff group that increased in size from approximately 15 fte in 2015 to 25 fte in 2020; whereas the number of PhD students and research funding remained stable throughout this period. The Research Unit increased its output of refereed journal papers from 156 in 2015 to 205 in 2020 and was responsible for 19 PhD theses per year (stable across the years). In addition to scientific publications, our research results are increasingly shared with society via debates, newspaper articles, radio, movies, and social media. Besides VENI, ASPASIA and Marie Curie Skłodowska personal grants, several staff members received individual signs of recognition and were invited to international conferences as keynote speakers. Of the staff members, 29 are members of an editorial board of an international peer-reviewed journal. Regarding our SWOT analyses, we are well equipped to be a key player in the role of animals in future food systems and society. We are confident that we can combat our weaknesses and threats by active participation in institutional working groups, which address institutional procedures and cost models. Moreover, we are actively developing new in-vitro tools, sensor-technology and big data approaches to reduce our dependency on animal experiments and increase the application of new state-of-the-art methodologies.

Case study: Resilient animals and sustainable systems

Critical transition periods for livestock include incubation, weaning, transport and changes from pregnancy to lactation. Our research on egg incubation conditions (i.e. CO2, O2, temperature, light and sound) led to recommendations that support bone development and reduce ascites in broilers. In addition, provision of food and water immediately after hatching improved metabolic and immune responses, which led to new legislation by the Dutch parliament and development of new husbandry systems for broilers together with industry (HatchCare (HatchTech), Patio system (Vencomatic)). Our research on piglets showed that the weaning transition can be eased by information transfer from sows stimulating early feed intake, and environmental enrichment. This led to the design of a unique group housing system for lactating sows and their piglets (the Family pig system). We have a strong track record in developing new welfare indicators, including those that reflect emotional states, and used Agent Based Modelling to understand underlying factors causing behavioural problems such as tail biting in pigs. We found that omitting or shortening their dry period benefits cow health and welfare with limited impact on economic performance (partial cash flows) and annual greenhouse gas emissions, and developed a decision support model to optimise dry period management at an individual cow level, which was made available to Dutch dairy farmers. We contributed to the development of sensor technology for longitudinal data in an automated manner enabling the prediction and assessment of loss of resilience and welfare problems, financially supported by national and international governmental organisations (e.g. European Fund for Regional Development (EFRO), Provinces, Ministry of Economic affairs, NWO) and multiple industrial partners as well as The Dutch Dairy board (ZuivelNL). The Dutch Animal Protection Society, as well as policy makers, monitor the outcomes of our studies. Our strategies to implement changes in practice support societal impact and discussions on complex ethical and sustainability issues. We regularly publish our work in popular media and give interviews.

Case study: Insects as pivotal components in the circular economy

Insects can fulfil a key role in re- and upcycling organic materials. Insects are protein-rich and energy dense, and when reared on organic materials inedible to humans (e.g. manure), insects themselves can be a suitable feed ingredient. The Dutch Research Council (NWO) supported several studies on insects, including quantification of bioconversion of animal manures as substrates for housefly and black soldier fly larvae, linked to environmental impact studies on gaseous emissions for development of mathematical models on sustainability. Studies on insects as feed for conventional production animals, and pet animals (funded by industry, Mars), and effects on production parameters, health and welfare are ongoing. Provision of live black soldier fly larvae increased broiler activity, decreased fearfulness and benefitted leg health; results already utilised by industry (e.g. Oerei) and agricultural cooperatives (e.g. Agrifirm). Provision of live larvae to pigs is ongoing. At this moment in Europe, production animals (other than fish) are only allowed to consume live, unprocessed insects. Studies on the utilization of insect meal to replace fish meal as a feed ingredient, especially for carnivorous fish, are ongoing and can have significant impacts on a circular economy. During the processing of insects, a fraction rich in chitin-bound protein remains poorly digestible by monogastrics but useful as by-pass protein for ruminants, potentially decreasing CH4 production, fulfilling the protein requirements of dairy cattle and replacing soybean meal. Thereby, insects can play a major role in a circular economy which hinges on the concept that materials are utilised to their full extent, aiming to eliminate waste.

Case study: Ecological intensification of pond aquaculture using dietary carbohydrates

The composition of aquaculture feeds still relies heavily on capture fisheries: almost one-third of the global fish catch is used in aquaculture feeds. The continuing growth of the aquaculture sector stimulates the use of locally available co-products of relatively low quality. Together with CGIAR, we developed the concept of 'nutritious pond feeds' aimed at valorising underutilised low-quality ingredients locally available in South-East Asia and Africa. Nutritious pond feeds are high in fibres and carbohydrates, which are only partially digested by the fish and - when excreted - provide energy to aquatic bacteria to break down feed wastes and liberate nutrients like nitrogen and phosphorus that stimulate the pond's natural food web. The concept was proven successful for Nile tilapia and shrimp kept in experimental ponds and on-farm in Bangladesh. Data have been integrated in the FeedCalculator;

an open access feed formulation app now used by local feed millers to formulate their own nutritious pond feeds for the lowest price. The Dutch Research Council (NWO) supported research on upgrading low quality ingredients in tilapia feeds by enzyme supplementation. Macro-nutrient and macro-mineral availability of non-starch polysaccharides (NSP) including fibres, strongly improve after application of enzymes especially in low quality tilapia diets. The inclusion of higher levels of carbohydrates requires a novel approach to evaluate energy in fish feeds. In collaboration with the feed industry, we developed net energy (NE) systems for several fish species and in 2019 Coppens/Alltech was the first partner to apply the NE concept to the composition of trout feed. Use of dietary carbohydrates for fish feed are one means of strengthening the development of circular, sustainable food systems.

Summary Population, Dynamics and Genomics

The research unit Population Dynamics and Genomics (PDG) consists of the chair groups Animal Breeding and Genomics (ABG), Marine Animal Ecology (MAE) and Quantitative Veterinary Epidemiology (QVE), and has been in place since January 2020. The mission of PDG is to generate knowledge and provide education and advice on the management of populations in a sustainable way for the benefit to humans. This mission is addressed by research within three main themes: 1) Sustainable animal breeding for production in resilient (eco)systems, 2) Preventing and managing emerging, epidemic and endemic infectious diseases, and 3) Management of small populations and threatened species in marine and terrestrial ecosystems. A key feature of PDG is the emphasis of the research focusing on the population level rather than on individual animals. By integrating quantitative genetics, genomics, eco-physiology, bioinformatics, transmission mechanisms, and modelling, PDG aims to increase insight into the biological mechanisms underlying phenotypic variation in animals, to facilitate managing ecosystem services, biodiversity and resilience, and to estimate the transmission and effect of different conditions and interventions on the transmission. The research of PDG addresses key questions related to populations in captivity and in the wild, for both terrestrial and aquatic systems. In our research, we use a variety of approaches including genetics, vaccination, and biosecurity and hygiene measures. One of our aims is to develop methods for the selection of production animal populations for improved efficiency, health and welfare while maintaining their genetic diversity. Knowledge on these aspects will enable breeding of efficient and healthy animals that perform optimally under a variety of conditions. For the genetic understanding, maintenance of genetic variation and improvement of managed populations in the wild (population and landscape genomics), we also use a wide variety of phenotypic and genomic information sources.

The work of PDG is of high societal relevance and directly contributes to several of the Sustainable Development Goals, i.e. Zero Hunger, Good Health and Well Being, Life Below Water and Life on Land. This societal relevance is also illustrated by the regular public outreach on timely subjects by the PDG staff. In the current pandemic, PDG was and is involved in several research projects studying the transmission of SARS-cov-2 among humans and the role of animals in the transmission. Likewise, over three billion people depend on marine and coastal biodiversity for their livelihoods and PDG contributes to science-based innovative solutions for the restoration and more sustainable use of marine ecosystems. Over the past decades, animal breeding has contributed significantly to the efficiency of animal production, with drastic reductions in its ecological footprint. The emphasis is on sustainable genetic improvement, also in developing countries and the tropics, by exploring, making use of, and developing new technologies (genomic prediction, genomics, and biotechnology).

We strive for high quality in our research and publications. Over the reporting period, the research unit has seen a consistently high number of PhD theses and refereed articles in leading journals in our domain. A high proportion of peer-reviewed articles are in the top 10% and 1% of cited publications in our fields. In recent years especially, the majority of our publications are open access and where possible the underlying data are made publicly available. While this sometimes is challenging because of the close collaboration with industry or confidentially of medical records, PDG nevertheless strives to make the relevant data available, enabling verification of the results.

The research unit has a unique range of expertise to address key research questions for populations in captivity and in the wild, for both terrestrial and aquatic systems. The strong collaboration with the Dutch breeding and animal health sectors and the other research institutes of ASG, and the active involvement within the three themes of the Next Level Animal Sciences program, enable PDG to remain a key player in this area for the future. We will continue to invest in young talent, in new PhDs and postdocs as well as junior staff members. To achieve these goals, PDG continues to put specific emphasis on obtaining personal grants for its staff (EU ERC and NWO Veni, Vidi, Vici grants). Within each of the three main research themes PDG has already secured funding, resulting in a strategic research portfolio with long-term projects that will provide the backbone of PDG. Finally, the new Horizon Europe programme offers many new opportunities to further strengthen the collaborative potential and international position of the PDG research unit.

Case study Societal impact: The NWO-TTW-Breed4Food Partnership program

The TTW-Breed4Food partnership program was initiated and financed by the Dutch funding agency Applied and Engineering Sciences (AES) and the 4 breeding companies within the Breed4Food consortium. Within this research program several characteristic elements of the PDG cluster come together: (1) The collaboration between the University and Research institutes (WLR), (2) The close collaboration with the 4 breeding companies of Breed4Food, (3) The quantitative genetics expertise with increasing focus on the use of artificial intelligence (AI) applications, (4) The genomics expertise increasingly focusing on whole genome sequencing and functional sequences in the genome and (5) The collaboration with other research groups and Universities with expertise in other disciplines such as Bioinformatics (Delft University), and AI (Universities of Groningen and Nijmegen). The program consisted of 5 individual projects with 6 PhD students and 3 Postdocs.

The research within these projects was aimed at improving our ability to predict phenotypes from genotypes and genome sequence data. Current animal breeding is based on genomic selection (GS) mostly within specific breeding lines. To further improve GS, it is important to be able to also use information from cross-bred individuals and the vast amount of phenotypic data being collected on these animals. Current GS basically is a black box approach that is particularly powerful within populations and less so across populations. The identification and use of the functional variants underlying the phenotypes therefore would enable GS to be used also across populations.

All 4 WUR PhD students within this program successfully defended their thesis, one of which was awarded a cum laude (Martijn Derks). Two of the PhD students (Martijn Derks and Pascal Duenk) have joined PGD as junior researcher/lecturers. The post-docs on the projects were also very successful and two of them (Mirte Bosse and Yvonne Wientjes) were awarded individual VENI grants. Both have been appointed to permanent positions.

Case study Scientific Aim: Sustainable animal breeding: The NWO-TTW Perspectief IMAGEN Project

The animal production sector faces the challenge of a radical transformation (Ministry of Agriculture, Nature and FoodQuality, LNV, 2018). In 2020 funding for a large NWO-TTW Perspective project (IMAGEN) was successfully obtained to address this challenge. The IMAGEN project aims to facilitate the transition towards sustainable livestock production by addressing the social behaviours of animals in groups, which will improve the health and welfare of the animals and reduce the ecological footprint of our food production. The IMAGEN project brings together scientific communities and industry from two completely unrelated fields: animal and veterinary sciences (WUR and Utrecht University), and computer vision and data sciences (Eindhoven University of Technology). Eindhoven University of Technology, Wageningen University & Research, Utrecht University and the University Medical Center (UMC) Utrecht collaborate intensively in a strategic knowledge alliance. The project uniquely integrates AI, computer vision, genetics and social interactions in livestock populations under field conditions. The close collaboration with the Dutch breeding industry, with global market shares of up to 40%, guarantees the global impact of this unique combination of technology and genetics. The overall aim of IMAGEN is to enable and stimulate a transition towards sustainable livestock production by addressing the social interactions between animals in social groups, improving their health and welfare and reducing the ecological footprint of food production.

Case study Scientific aim: Preventing infectious diseases: breeding against infectious diseases (Digital Dermatitis as example)

This project, financed by an NWO grant in the recent past (More with less programme) builds on the earlier and on-going studies of social interactions and on the modelling of infection dynamics, generating further research synergy within our cluster. To improve genetic selection against infectious diseases, we worked on the integration of quantitative genetic models with epidemiological models of disease transmission, in the near future to be supported by automated data collection on individual disease status. Recently, in a joint modelling effort from breeders and epidemiologists we have also shown that selection for resistance against infectious diseases can

achieve eradication of endemic infectious diseases (e.g. Digital Dermatitis). We are ready to start investigating how we can automate phenotyping cattle for DD (financed in the Next Level Animal Science investment) and calculate effect of genotypes from that. The latter step is very important as the underlying genotypes have major indirect genetic effects. We are further developing the theory on the breeding side explaining the difference between breeding values for infection status and breeding value for prevalence; the point being that the expected prevalence of a population cannot be computed from the individual breeding values for infection. In the breeding value for prevalence the individual's contribution to a higher or lower infection probability for other animals in the population is also incorporated. Epidemiologically it is also relevant that DD persists in the environment and thus environmental decay of infectivity in the environment needs to be estimated.

Case study Scientific aim: Managing small populations: Resilience of the Richest reefs

Globally, coral reefs are under severe threat. Tourism is increasingly recognised as both a driver as well as a strategy to reduce the threats to coral reefs. The combination of climatic changes and wider anthropogenic stressors, such as tourism-related pollution, erode resilience of coral reefs and raise the risk of widespread extinction. At the same time, some reefs are still well- functioning, providing a window of opportunity to save those that are threatened, even though it is closing fast. With an interdisciplinary team, the recently funded INREF project: Resilience of the richest reefs aims to provide the knowledge to preserve global coral reefs. In a collaboration between natural and social scientists, and with several stakeholders, we will investigate how to define and operationalise a safe operating space for tourism in coral reef ecosystems. On the one hand, uncontrolled tourism is a stressor as it intensifies use, which leads to increased pollution and physical disturbances to the reef. On the other hand, if carefully managed, tourism can provide the necessary funding to enforce and manage MPAs and give incentives to users to stop engaging in unsustainable practices, such as wasteful fishing practices. Additionally, climate change – a key driver - cannot be controlled locally, but tourism impacts can be. Our general aim is to understand, build and manage the resilience of tourism in a selection of marine protected areas (MPAs) in Indonesia and the Dutch Caribbean to contribute to global sustainable development, biodiversity and climate targets. In this project MPAs around coral reefs are studied as social-ecological systems with complex feedbacks between the socioeconomic and ecological subsystem. This will involve a careful mapping of ecological and physical processes, such as nutrient flows and food web dynamics. At the same time, a careful understanding of socio-economic processes, such as distribution of benefits and emerging discourses, is required. We will co-develop adaptive management plans that carefully reflect the local context with stakeholders. Furthermore, we will investigate how tourism value chains can be optimised to benefit local communities and leveraged to foster sustainable practices and a greater funding base for MPAs. Institutional capacity will be built at universities, institutes and NGOs in Indonesia and the Dutch Caribbean through joint sandwich PhDs, technical workshops and scholarships. Generally, this project develops a critical academic knowledge base on the potential and limits of tourism to contribute to resilient marine conservation, as well as practical monitoring and policy. Collectively, these insights will help to inform transformation towards sustainability that will save our global reefs in a time of climatic changes and volatile tourism dynamics.