Preface to the Volume

This book provides a much needed update on the Springer volume entitled *Polarized Light in Animal Vision—Polarization Patterns in Nature* (Horváth and Varjú 2004). Much has happened in this field in the last 10 years. The main goal of this volume is to summarise new results but also place these in the context of past work. Each of the chapters is written by relevant experts in each field and includes a thorough literature survey and explores future research directions. Literature prior to 2004 is also extensively cited here; however, we focus mainly on the results obtained in the last decade. Other useful reviews of the field that have appeared in this period include the special issue 'New directions in biological research on polarized light' in the *Philosophical Transactions of the Royal Society B* edited by Marshall et al. (2011) and the review by Wehner and Labhart (2006) on polarisation vision in the book entitled *Invertebrate Vision* edited by Warrant and Nilsson. The book of Können (1985) entitled *Polarized Light in Nature* and the booklet of Pye (2001) entitled *Polarised Light in Science and Nature* introduce the reader to the world of light polarisation and some of its applications.

This book is intended for anyone interested in animal vision, environmental optics, polarised light and polarisation sensitivity, including biologists, physiologists, ecologists and physicists. In particular, the recent advances in imaging polarimetry, which translate the parameters of polarisation into colour, allow the reader to understand the information within the polarisation patterns of the optical environment not directly accessible to the human visual system. Such instrumentation has also allowed polarisation research to advance rapidly, as we can now glimpse this previously hidden world.

Part I of the book deals with the polarisation vision in animals and humans. Chapter 1 gives an overview on the historical perspective of polarisation vision research. The subject of Chap. 2 is polarisation vision and orientation of ball-rolling dung beetles, which is governed partly by sky polarisation. Dung beetles, unlike most insect navigators, do not need to locate a stationary nest at the end of their foraging journey. Their main task is to roll their dung ball from the dung source as quickly and as far from potential competitors as possible. That is along a straight line to avoid the attack of other dung beetles that might steal the ready-made ball.

During their straight-line orientation, they rely on celestial compass cues to move along straight paths and can even achieve this at night using both moon and starlight. Chapter 3 summarises recent knowledge regarding polarisation vision in the most extensively studied groups such as ants, bees and wasps, using behavioural, anatomical and physiological approaches. Chapter 4 deals with polarisation-based behaviour, polarisation detectors and polarised-light processing in the brains of desert locusts, Monarch butterflies, crickets, houseflies and fruit flies. Polarisation sensitivity is also considered in the context of colour vision.

The topic of Chap. 5 is polarisation vision in aquatic insects. The recently discovered polarisation sundial of these insects explains why they fly at low and/or high sun elevations at different times of the day or evening. Polarisation-based water detection and positive polarotaxis (attraction to horizontally polarised light) in non-biting midges, dragonflies, mayflies and tabanid flies are surveyed. It is shown that the polarotaxis in egg-laying yellow fever mosquitoes is odour masked. Finally, it is demonstrated how negative polarotaxis in desert locusts can hinder flying over the sea.

Chapter 6 deals with the potential for circular polarisation vision of scarab beetles. The appearance of circular polarisation in the abiotic and biotic optical environment is surveyed, and the polarisation characteristics of circularly polarising scarab beetle cuticle, as measured by imaging polarimetry, are presented. Finally, behavioural evidence for the lack of circular polarisation sensitivity in four scarab species with a circularly polarising exocuticle—*Anomala dubia*, *A. vitis* (Coleoptera, Scarabaeidae, Rutelinae) and *Cetonia aurata*, *Protaetia cuprea* (Coleoptera, Scarabaeidae, Cetoniinae)—is presented. Previously suggested circular polarisation sensitivity in the scarab species *Chrysina gloriosa* is considered and criticised.

Chapter 7 is about the polarisation vision of crustaceans. It surveys the polarised light sources for crustaceans, the structural basis and neural processing of polarisation sensitivity and polarisation-based behaviours in crustaceans. Chapter 8 details polarisation sensitivity and its functions in cephalopods. Chapter 9 summarises the recent results about the structural and neural mechanisms of polarisation sensitivity in fishes, the functions of which are object recognition, navigation and camouflage. Chapter 10 is devoted to polarisation sensitivity in amphibians. It describes amphibian photoreception, the pineal complex, the use of polarisation sensitivity in orientation and the possible connection between polarisation sensitivity and magnetoreception. Chapter 11 surveys the photoreceptors and mechanisms underlying polarisation sensitivity in crocodiles, lizards and snakes. It also considers the possible use of polarisation sensitivity for orientation in reptilian migration. Chapter 12 examines polarisation vision in birds. It deals with avian celestial orientation and migration, the importance of skylight polarisation in avian compass calibration and the behavioural evidence for polarisation sensitivity in birds.

Chapter 13 examines some of the possible interactions between colour vision and polarisation vision. It is shown how polarisational false colours could help visual discrimination between smooth (shiny) and rough (matte) leaf surfaces but cannot unambiguously code surface orientation. This chapter also demonstrates how uniformly polarisation-sensitive retinas can perceive polarisation-induced false colours. Chapter 14 reviews the available knowledge of human polarisation sensitivity. It deals with Haidinger's and Boehm's brushes and the potential mechanisms underlying these visual phenomena. Some applications of human polarisation sensitivity are also considered.

Part II of the book concerns mainly descriptions of the physics of polarised light in nature but with specific reference to animal polarisation vision. Chapter 15 is about underwater polarisation induced by scattering hydrosols. It considers the sources of polarised light in the ocean, the transmission (refraction) of polarised light at the air–water interface, the attenuation of polarisation by scattering and absorption, the effect of water turbidity on polarisation, measurements and modelling of polarisation in clear and turbid waters and the polarisation-based response of animals living in turbid waters.

Chapter 16 presents polarisation patterns of freshwater bodies and their likely role in guiding water detection in aquatic insects. Polarisation visibility of water surfaces is also measured and calculated as a function of the solar elevation angle, which explains why water-seeking polarotactic aquatic insects might fly at low and/or high sun elevations.

Chapter 17 presents the polarisation characteristics of forest canopies and shows how the azimuth of the foliage-occluded sun can be determined from the pattern of the direction of polarisation of sunlit foliage canopies. Why dusk-active cockchafers sense downwelling polarisation in the green part of the spectrum is also explored.

Chapter 18 demonstrates the robustness of the celestial E-vector pattern, which is the basis of orientation of many polarisation-sensitive animals and the basis for hypothetical sky-polarimetric Viking navigation. It is shown how well the Rayleigh model describes the pattern of the angle of polarisation of clear and cloudy skies. The polarisation characteristics of foggy, partly cloudy, overcast, twilight and eclipsed skies are also revealed including fogbows and the 'water-skies' above arctic open waters. The anomalous sky polarisation due to forest fire smoke is also presented as a way of explaining why some polarisation-sensitive insects disorient under smoky skies. Similarly, the changed sky polarisation during total solar eclipses is discussed with respect to its influence on the orientation of honeybees. Finally, it is shown how skylight polarisation is transmitted through Snell's window on flat water surfaces.

Chapter 19 surveys the linearly and circularly polarised signals from terrestrial and aquatic animals, such as butterflies, beetles, flies, dragonflies, spiders, fiddler crabs, birds, stomatopods, cephalopods and fishes.

Chapter 20 is devoted to anthropogenic polarisation and polarised light pollution (PLP), which induces polarised ecological traps for polarotactic insects, such as water beetles, aquatic bugs, dragonflies, mayflies, caddisflies and stoneflies. It is shown that the maladaptive attractiveness of solar panels to polarotactic insects can be reduced by surface fragmentation due to white grid patterns. The PLP of asphalt surfaces, black horizontal agricultural plastic sheets, glass surfaces, shiny black gravestones and dark car bodies is considered in detail. The insectivorous animals (birds, spiders and bats) lured by the polarotactic insects attracted to polarised-light-polluting artificial surfaces are also surveyed. The questions of why vertical glass panes attract polarotactic insects and why these insects remain on such glass surfaces after landing are answered. It is shown how the vertically polarised mirror image of bridges on the water surface can deceive flying mayflies and what are the ecological consequences. Finally, it is explained why strongly polarising black and burnt stubble fields do not attract polarotactic aquatic insects.

Part III of the book summarises several practical applications of polarisation vision and patterns. Chapter 21 surveys existing knowledge about polarisation as a guiding cue for oviposition in non-biting midges (chironomids) and mosquitoes. Chapter 22 presents recent research about linearly polarised light and its use as a guiding cue for water detection and host finding in tabanid flies. It is shown that bright animal coats are only weakly attractive to polarotactic tabanids. A new explanation of the evolutionary advantage of zebra stripes and spotty fur patterns is also presented. We show that stripes and spots make ungulates unattractive to host-seeking female tabanid flies, and stripes disrupt the odour attractiveness of host animals to tabanids.

Chapter 23 surveys novel polarisation-based insect traps. Polarisation chironomid traps are initially considered, followed by three different polarisation tabanid traps, which are presented as a new technique of horsefly control to capture host- and water-seeking tabanids.

Chapter 24 is devoted to polarisation cloud detection with imaging polarimetry. It reviews the full-sky photometric imagers and photometric cloud detection algorithms and examines the airborne PARASOL and POLDER polarisation cloud detectors. The applications of polarisation cloud detection for the determination of cloud distribution, cloud-base height, solar forecasting, aerosol characterisation, Viking navigation and the study of animal orientation are also presented.

Chapter 25 examines the possibility and the atmospheric prerequisites of hypothetical sky-polarimetric Viking navigation. Modern sky-polarimetric navigation, the medieval Norse sailing routes, the climatic conditions in the Viking era and the presumed nature of the enigmatic Viking sunstone are initially considered. Then, the possibility of sky-polarimetric Viking navigation under various weather conditions is discussed. The hypothesised Viking solar navigation instruments (horizon board, Viking sun compass, twilight board, medieval twilight navigation toolkit, sun-shadow board with a sundial and millennium-old carved schedule) are all surveyed. Some atmospheric-optical phenomena providing alternative navigation cues are also summarised.

Additional photographs, polarisation patterns, tables, graphs and video films are provided electronically.

We dedicate this book to the late Professors Talbot H. Waterman and Dezso Varju and to Professor Rudiger Wehner on the occasion of his 75th birthday.

The oeuvre of Waterman was appreciated recently by Cronin, Marshall and Wehling (2011). Dezső Varjú, the mentor of the editor of this volume, Gábor Horváth, and one of the authors of the book *Polarized Light in Animal Vision—Polarization Patterns in Nature*, unfortunately died in August 2013. Finally, we greet Professor Rudiger Wehner on the occasion of his 75th birthday.

Budapest, Hungary — Gábor Horváth
Perth, Australia — Shaun Collin
Brisbane, Australia — Justin Marshall
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