Handbook of Environmental Engineering 19

Lawrence K. Wang
Mu-Hao Sung Wang
Yung-Tse Hung
Nazih K. Shammas *Editors*

Environmental and Natural Resources Engineering

Springer

Handbook of Environmental Engineering

Volume 19

Series Editors

Lawrence K. Wang
PhD, Rutgers University, New Brunswick, NJ, USA
MS, University of Rhode Island, Kingston, RI, USA
MSCE, University of Missouri, Rolla, MO, USA
BSCE, National Cheng Kung University, Tainan, Taiwan, ROC

Mu-Hao Sung Wang
PhD, Rutgers University, New Brunswick, NJ, USA
MS, University of Rhode Island, Kingston, RI, USA
BSCE, National Cheng Kung University, Tainan, Taiwan, ROC

The past 30 years have seen the emergence of a growing desire worldwide to take positive actions to restore and protect the environment from the degrading effects of all forms of pollution: air, noise, solid waste, and water. The principle intention of the Handbook of Environmental Engineering (HEE) series is to help readers formulate answers to the fundamental questions facing pollution in the modern era, mainly, how serious is pollution and is the technology needed to abate it not only available, but feasible. Cutting-edge and highly practical, HEE offers educators, students, and engineers a strong grounding in the principles of Environmental Engineering, as well as providing effective methods for developing optimal abatement technologies at costs that are fully justified by the degree of abatement achieved. With an emphasis on using the Best Available Technologies, the authors of these volumes present the necessary engineering protocols derived from the fundamental principles of chemistry, physics, and mathematics, making these volumes a must have for environmental pollution researchers.

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Lawrence K. Wang • Mu-Hao Sung Wang
Yung-Tse Hung • Nazih K. Shammas
Editors

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Editors
Lawrence K. Wang
Rensselaer Polytechnic Institute
Troy, NY, USA
Lenox Institute of Water Technology
Newtonville, NY, USA

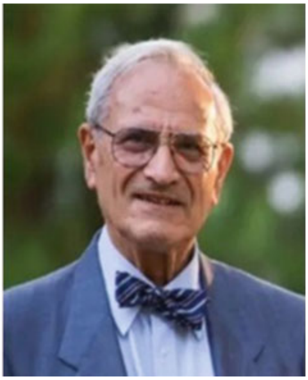
Mu-Hao Sung Wang
Lenox Institute of Water Technology
Newtonville, NY, USA
Krofta Engineering Corporation
Lenix, MA, USA

Yung-Tse Hung
Department of Civil and Environmental
Engineering, Cleveland State University
Cleveland, OH, USA

Nazih K. Shammas
Lenox Institute of Water Technology
Newtonville, NY, USA
Krofta Engineering Corporation
Lenix, MA, USA

ISSN 2512-1359 ISSN 2512-1472 (electronic)
Handbook of Environmental Engineering
ISBN 978-3-030-54625-0 ISBN 978-3-030-54626-7 (eBook)
https://doi.org/10.1007/978-3-030-54626-7

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland



The Handbook of Environmental Engineering (HEE), Volume 19, Environmental and Natural Resources Engineering*, is published in memory of both Dr. Nazih K. Shammas (Left) and Dr. Donald B. Aulenbach (Right), who contributed significantly as the authors/coeditors the HEE series and both were environmental humanitarian engineering professors at the Lenox Institute of Water Technology (LIWT), USA, for two decades. Dr. Aulenbach also taught at the Rensselaer Polytechnic Institute (RPI), USA. Their former colleagues of HEE, LIWT, and RPI and their friends have jointly contributed to this HEE*

Volume 19 to salute and forever remember these two outstanding scholars.

An Alternative Poem of "Thousand Winds"
For: Environmental Scholars gone with Winds like beautiful autumn leaves
By: Lawrence K. Wang and Mu-Hao Sung Wang

Do not stand at my grave and weep
I am not there, I do not sleep
I am in a thousand winds that blow
I am the fresh air up there
I am the fertile soil on land
I am the swimming fish in water

When you find me in the autumn's hush
I am in the graceful rush
Of beautiful leaves in circling current
I am the scholar with passion
I am in the homes with love
I am on the Internet
I am the leaves that fly

I am in each lovely thing

Do not stand at my grave and cry
I am not there, I do not die

Note: Original "Thousand Winds" author was Mary Elizabeth Frve.

Preface

The past 75 years have seen the emergence of a growing desire worldwide that positive actions be taken to restore and protect the environment from the degrading effects of all forms of pollution – air, water, soil, thermal, radioactive, and noise. Since pollution is a direct or indirect consequence of waste, the seemingly idealistic demand for "zero discharge" can be construed as an unrealistic demand for zero waste. However, as long as waste continues to exist, we can only attempt to abate the subsequent pollution by converting it to a less noxious form. Three major questions usually arise when a particular type of pollution has been identified: (1) How serious are the environmental pollution and water resources crisis? (2) Is the technology to abate them available? and (3) Do the costs of abatement justify the degree of abatement achieved for environmental protection and natural resources conservation? This book is one of the volumes of the Handbook of Environmental Engineering series. The principal intention of this series is to help readers formulate answers to the above three questions.

The traditional approach of applying tried-and-true solutions to specific environmental and water resources problems has been a major contributing factor to the success of environmental engineering and has accounted in large measure for the establishment of a "methodology of pollution control." However, the realization of the ever-increasing complexity and interrelated nature of current environmental problems renders it imperative that intelligent planning of pollution abatement systems be undertaken. Prerequisite to such planning is an understanding of the performance, potential, and limitations of the various methods of environmental protection available for environmental scientists and engineers. In this series of handbooks, we will review at a tutorial level a broad spectrum of engineering systems (natural environment, processes, operations, and methods) currently being utilized, or of potential utility, for pollution abatement, environmental protection, and natural resources conservation. We believe that the unified interdisciplinary approach presented in these handbooks is a logical step in the evolution of environmental engineering.

Treatment of the various engineering systems presented will show how an engineering formulation of the subject flows naturally from the fundamental principles and theories of chemistry, microbiology, physics, and mathematics. This emphasis on fundamental science recognizes that engineering practice has in recent years become more firmly based on scientific principles rather than on its earlier dependency on empirical accumulation of facts. It is not intended, though, to neglect empiricism where such data lead quickly to the most economic design; certain engineering systems are not readily amenable to fundamental scientific analysis, and in these instances we have resorted to less science in favor of more art and empiricism.

Since an environmental natural resources engineer must understand science within the context of applications, we first present the development of the scientific basis of a particular subject, followed by exposition of the pertinent design concepts and operations, and detailed explanations of their applications to natural resources conservation or environmental protection. Throughout the series, methods of mathematical modeling, system analysis, practical design, and calculation are illustrated by numerical examples. These examples clearly demonstrate how organized, analytical reasoning leads to the most direct and clear solutions. Wherever possible, pertinent cost data or models have been provided.

Our treatment of environmental natural resources engineering is offered in the belief that the trained engineer should more firmly understand fundamental principles, be more aware of the similarities and/or differences among many of the engineering systems, and exhibit greater flexibility and originality in the definition and innovative solution of environmental system problems. In short, the environmental and natural resources engineers should by conviction and practice be more readily adaptable to change and progress.

Coverage of the unusually broad field of environmental natural resources engineering has demanded an expertise that could only be provided through multiple authorships. Each author (or group of authors) was permitted to employ, within reasonable limits, the customary personal style in organizing and presenting a particular subject area; consequently, it has been difficult to treat all subject materials in a homogeneous manner. Moreover, owing to limitations of space, some of the authors' favored topics could not be treated in great detail, and many less important topics had to be merely mentioned or commented on briefly. All authors have provided an excellent list of references at the end of each chapter for the benefit of the interested readers. As each chapter is meant to be self-contained, some mild repetition among the various texts was unavoidable. In each case, all omissions or repetitions are the responsibility of the editors and not the individual authors. With the current trend toward metrication, the question of using a consistent system of units has been a problem. Wherever possible, the authors have used the British system (fps) along with the metric equivalent (mks, cgs, or SIU) or vice versa. The editors sincerely hope that this redundancy of units' usage will prove to be useful rather than being disruptive to the readers.

The goals of the Handbook of Environmental Engineering series are: (1) to cover entire environmental fields, including air and noise pollution control, solid waste processing and resource recovery, physicochemical treatment processes, biological treatment processes, biotechnology, biosolids management, flotation technology, membrane technology, desalination technology, water resources, natural control processes, radioactive waste disposal, hazardous waste management, and thermal pollution control; and (2) to employ a multimedia approach to environmental conservation and protection since air, water, soil, and energy are all interrelated.

This book (Volume 19) and its two sister books (Volumes 17 and 20) of the Handbook of Environmental Engineering series have been designed to serve as natural resources engineering reference books as well as supplemental textbooks. We hope and expect they will prove of equal high value to advanced undergraduate and graduate students, to designers of natural resources systems, and to scientists and researchers. The editors welcome comments from readers in all of these categories. It is our hope that the three natural resources engineering books will not only provide information on natural resources engineering, but will also serve as a basis for advanced study or specialized investigation of the theory and analysis of various natural resources systems.

This book, *Environmental and Natural Resources Engineering, Volume 19*, covers the topics on understanding, conservation, and protection of precious natural resources – bees; waste reclamation for reuse; biological processes for water resources protection and water reuse; removal of endocrine disruptors for environmental protection; cooling and reuse of thermal discharges; basic hydrology, water resources, and DAF boat plant for lake restoration; cadmium detoxification by sintering with ceramic matrices; treatment of vegetable oil refining wastes; environmental engineering education; environmental control of pests and vectors; new book reviews; and glossary of environmental and natural resources engineering.

This book's first sister book, *Natural Resources and Control Processes, Volume 17*, covers the topics on management of agricultural livestock wastes for water resources protection; application of natural processes for environmental protection; proper deep well waste disposal; treating and managing industrial dye wastes; health effects and control of toxic lead in the environment; municipal and industrial wastewater treatment using plastic trickling filters for BOD and nutrient removal; chloride removal for recycling fly ash from municipal solid waste incinerator; recent evaluation of early radioactive disposal and management practice; recent trends in the evaluation of cementitious material in radioactive waste disposal; extensive monitoring system of sediment transport for reservoir sediment management; and land and energy resources engineering glossary.

This book's second sister book, *Integrated Natural Resources Management, Volume 20,* covers the topics on effect of global warming, climate change on glacier and salmons; community-based latrine development with Engineers Without Borders – USA; surface water quality and analysis; water quality control of tidal rivers and estuaries; treatment of electrical and electronic component manufacturing wastes; geographic information systems and remote sensing applications in environmental and water resources; investigation and management of water losses from wet infrastructure; lake restoration and acidic water control; biohydrogen production through mixed culture dark anaerobic fermentation of industrial waste; agricultural waste-derived absorbents for decontamination of heavy metals; removal of heavy metal ions using magnetic materials; and biohydrogen production from lignocelluosic biomass by extremely halotolerant bacterial communities.

The editors are pleased to acknowledge the encouragement and support received from Mr. Aaron Schiller, Executive Editor of the Springer Nature Switzerland, and his colleagues during the conceptual stages of this endeavor. We wish to thank the contributing authors for their time and effort, and for having patiently borne our reviews and numerous queries and comments. We are very grateful to our respective families for their patience and understanding during some rather trying times.

Newtonville, NY, USA Lawrence K. Wang
Newtonville, NY, USA Mu-Hao Sung Wang
Cleveland, OH, USA Yung-Tse Hung
Pasadena, CA, USA Nazih K. Shammas

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About the Editors

Lawrence K. Wang has more than 28 years of experience in facility design, environmental sustainability, natural resources, resources recovery, global pollution control, construction, plant operation, and management. He has expertise in water supply, air pollution control, solid waste disposal, water resources, waste treatment, and hazardous waste management. He is a retired acting President/director/VP of the Lenox Institute of Water Technology, Krofta Engineering Corporation, and Zorex Corporation, respectively, and was an Assistant Professor/Associate Professor/Professor of Rensselaer Polytechnic Institute, Stevens Institute of Technology, and the University of Illinois, respectively, in the USA. He has represented the US government to serve the United Nations Industrial Development Organization (UNIDO) as a Senior Advisor in Vienna, Austria. Dr. Wang is the author of over 700 papers and 45 books, and is credited with 24 US patents and 5 foreign patents. He received his BSCE degree from National Cheng-Kung University, Taiwan, ROC; his two MS degrees from the University of Missouri (Missouri University of Science and Technology) and the University of Rhode Island, USA; and his PhD degree from Rutgers University, USA. Currently he is the chief series editor of the *Advances in Industrial and Hazardous Wastes Treatment* series (CRC Press of Taylor & Francis Group), the *Handbook of Environmental Engineering* series (Springer), the *Evolutionary Progress in Science, Technology, Engineering, Arts, and Mathematics* series (Lenox Institute Press), and the *Environmental Science, Technology, Engineering and Mathematics* series (Lenox Institute Press). He is also the coeditor of the *Handbook of Environment and Waste Management* series (World Scientific) and the coauthor of the *Water and Wastewater Engineering* series (John Wiley).

Mu-Hao Sung Wang has been an engineer, editor, and professor serving private firms, governments, and universities in the USA and the Republic of China (ROC) for over 25 years. She is a licensed professional engineer and a diplomate of the American Academy of Environmental Engineers. Her publications have been in the areas of water quality, modeling, environmental sustainability, waste management, NPDES, flotation, and analytical methods. Dr. Wang is the author of over

50 publications and an inventor of 14 US and foreign patents. She received her BSCE degree from National Cheng Kung University, Taiwan, ROC; her MSCE degree from the University of Rhode Island, USA; and her PhD degree from Rutgers University, USA. She was an Adjunct Associate Professor at Stevens Institute of Technology, NJ, USA; an Adjunct Professor at National Cheng Kung University, Taiwan, ROC, and a professor at the Lenox Institute of Water Technology, MA, USA. She is the co-series editor of the *Handbook of Environmental Engineering* series (Springer), and the coeditor of the *Environmental Science, Technology, Engineering and Mathematics* series (STEM) (Lenox Institute Press). She is a member of AWWA, NEWWA, WEF, and OCEESA.

Yung-Tse Hung has been a professor of civil engineering at Cleveland State University since 1981. He is a fellow of the American Society of Civil Engineers and has taught at 16 universities in 8 countries. His research interests and publications have been involved with biological processes and industrial waste treatment. Dr. Hung is credited with over 470 publications and presentations on water and wastewater treatment. He received his BSCE and MSCE from National Cheng-Kung University, Taiwan, and his PhD from the University of Texas at Austin, USA. He is the editor of *International Journal of Environment and Waste Management, International Journal of Environmental Engineering,* and *International Journal of Environmental Engineering Science.*

Nazih K. Shammas was an environmental consultant and professor for over 45 years. He was an ex-dean/director of the Lenox Institute of Water Technology and an advisor to Krofta Engineering Corporation, USA. Dr. Shammas was the author of over 250 publications and 16 books in the field of environmental engineering. He had experience in environmental planning, curriculum development, teaching, scholarly research; and had expertise in water quality control, wastewater reclamation and reuse, physicochemical and biological processes, and water and wastewater systems. He received his BE degree from the American University of Beirut, Lebanon; his MS degree from the University of North Carolina at Chapel Hill, and his PhD degree from the University of Michigan, USA. He was the coeditor of the *Advances in Industrial and Hazardous Wastes Treatment* series (CRC Press of Taylor & Francis Group), the *Handbook of Environmental Engineering* series (Springer), the *Environmental Science, Technology, Engineering and Mathematics* series (Lenox Institute Press), and the *Handbook of Environment and Waste Management* series (World Scientific). In addition, Dr. Shammas was the coauthor of the *Water and Wastewater Engineering* series (John Wiley).

Contributors

Donald B. Aulenbach PhD, PE, DEE Rensselaer Polytechnic Institute, Troy, NY, USA
Lenox Institute of Water Technology, Lenox, MA and Newtonville, NY, USA

Henry R. Bungay III PhD H. P. Isermann Department of Chemical and Biological Engineering, Rensselaer Polytechnic Institute, Troy, NY, USA

Diyun Chen PhD School of Environmental Science and Engineering, Guangzhou University, Guangzhou, China

Erika J. Clesceri PhD Bureau for Democracy, Conflict and Humanitarian Assistance, US Agency for International Development, Washington, DC, USA

Lenore S. Clesceri PhD Department of Biology, Rensselaer Polytechnic Institute, Troy, NY, USA

James Eldridge Sales Department, Lantec Product, Agoura Hills, CA, USA

Yung-Tse Hung PhD, PE, DEE, F-ASCE Department of Civil and Environmental Engineering, Cleveland State University, Cleveland, OH, USA

Devrim Kaya PhD Department of Civil and Environmental Engineering, University of Maryland, College Park, MD, USA

Cynthia Li MS Lenox Institute of Water Technology, Lenox, MA and Newtonville, NY, USA

Kathleen Hung Li MS NEC Business Network Solutions, Inc., Irving, TX, USA

Nazih K. Shammas PhD Lenox Institute of Water Technology, Lenox, MA and Newtonville, NY, USA
Krofta Engineering Corporation, Lenox, MA, USA

Kaimin Shih PhD Department of Civil Engineering, The University of Hong Kong, Hong Kong, China

William W. Shuster PhD Department of Chemical and Environmental Engineering, Rensselaer Polytechnic Institute, Troy, NY, USA

Minhua Su PhD School of Environmental Science and Engineering, Guangzhou University, Guangzhou, China

Jerry R. Taricska PhD, PE Environmental Engineering Department, Hole Montes, Inc., Naples, FL, USA

Lawrence K. Wang PhD, PE, DEE Lenox Institute of Water Technology, Lenox, MA and Newtonville, NY, USA
Rensselaer Polytechnic Institute, Troy, NY, USA
Krofta Engineering Corporation, Lenox, MA, USA

Mu-Hao Sung Wang PhD, PE, DEE Lenox Institute of Water Technology, Lenox, MA and Newtonville, NY, USA
Krofta Engineering Corporation, Lenox, MA, USA

Chapter 1
Understanding, Conservation, and Protection of Precious Natural Resources: Bees

Cynthia Li

Contents

Abstract This chapter concerns the role of pollinators, especially bees, in relation to our agriculture and economy. Besides being a critical participant in the reproductive process of most flowering plants, the bees' pollination services increase flowering crop yields, improve nutritional quality, and contribute significantly to the global economy. However, beekeepers that manage the domesticated European honey bee had noticed that huge numbers of their bees were dying in recent years, and apiculture is closely wedded to agriculture. Honey bees suffer from a variety of maladies attributed to pesticides, climate change, parasites, and disease, all of which contribute to increased bee mortality and catastrophic hive death such as Colony Collapse Disorder (CCD). A number of these issues appear to affect wild pollinators

C. Li (✉)
Lenox Institute of Water Technology, Newtonville, NY, USA
e-mail: Cynthia.Li@mnsu.edu

L. K. Wang, M. -H. S. Wang, Y. -T. Hung, N. K. Shammas (eds.),
Environmental and Natural Resources Engineering, Handbook of Environmental Engineering 19, https://doi.org/10.1007/978-3-030-54626-7_1

as well. In order to conserve and protect our pollinator resources, this chapter describes a number of major stressors that lead to bee mortality and offers suggestions to improve bee and ultimately general pollinator survival. Recommended actions for beekeepers include adoption of honey bee strains that are bred for specific climates and survival traits as well as maintaining diverse forage around the apiary. Farmers are recommended to maintain areas of wild plants for diverse foraging sources, where a healthy bee diet also aids in crop pollination. In order to protect food availability, control prices, and support agricultural sustainability, governments can review ongoing research concerning known bee and pollinator stressors and implement legislation and guidelines to control human-created stressors such as pesticides while encouraging pollinator-friendly land management.

Keywords Pollinators · Pollination · Wild bees · Honey bees · Agriculture · Crops · Bee conservation and protection

Acronyms

ABPV	Acute Bee Paralysis Virus
AIV	Apis Iridescent Virus
ARS	Agricultural Research Service
CCD	Colony Collapse Disorder
CRP	European Union Conservation Reserve Program
DWV	Deformed Wing Virus
EU€	European Union Euro
FAO	Food and Agriculture Organization of the United Nations
IAPV	Israeli Acute Paralysis Virus
IPCC	Intergovernmental Panel on Climate Change
KBV	Kashmir Bee Virus
NASS	National Agricultural Statistics Service
NRCS	National Resources Conservation Service
NWRS	National Wildlife Refuge System
OPMP	USDA's Office of Pest Management Policy
US EPA	United States Environmental Protection Agency
US FWS	United States Fish and Wildlife Service
US$	United States Dollar
USDA	United States Department of Agriculture
VSH	Varroa-Sensitive Hygiene

1 Introduction

Pollinators are animals that allow 75% of flowering plants to reproduce; these plants include most fruits, vegetables, and nuts, where 87 of the leading 115 food crops are dependent on pollination services, where pollinators contribute an estimated one-third of global food production. Pollinators also play a key role in our agricultural economy, where they contributed more than $24 billion to the United States' economy in 2014, and honey bee pollination services specifically contributed more than $15 billion.

There are thousands of bee species. Most wild (native) bees in America are solitary. Honey bees, our most commonly managed pollinator, were imported to the Americas from Europe during colonial times in the 1600s. These are called European or Western honey bees; in this chapter, we will refer to them as European honey bees.

Honey bees are social insects; each colony has one queen, several drones, and thousands of worker bees living in a wax comb hive that they built themselves. In this hive, they store food and rear their brood (eggs, larvae, and pupae). Work responsibilities are caste based. The queen bee is responsible for reproduction and maintaining colony population; a drone's sole responsibility is to mate with a queen; worker bees do all other duties in maintaining the colony. Worker bee responsibilities include rearing the brood, caring for the queen, maintaining the wax comb structure, defending the colony, and foraging. Plant pollination occurs when worker bees are foraging on their flowers. The nectar and pollen gained from foraging are prepared and stored in the hive as the primary food supplies, where the nectar is converted to honey. When flowers begin to bloom again in the spring, the queen begins to lay eggs as worker bees leave the hive to forage and pollinate plants along the way, continuing the cycle. How do honey bees execute their colony responsibilities in a systematic way? They communicate with each other using pheromones and dances. Pheromones are chemical substances secreted from the sender's glands and received by the recipient's antennae or other body parts. All colony members from queen to even brood members can produce pheromones. Besides pheromones, honey bees also perform different dances to convey information or request services. The most famous dance is the "waggle dance," which conveys the direction and distance of a food resource.

For a very long time, the majority of honey bees in the Americas had been European honey bees. However, a scientist in Brazil imported pure African honey bees in 1956 with the intention of breeding more tropically adapted honey-producing bees. Just 1 year later, 26 African queen bees escaped into the wild. Since then, those African queens have hybridized with feral European honey bee populations, becoming Africanized honey bees (AHBs). Six decades later, Africanized honey bees have spread from South America through Central America and to North America. By 2009, Africanized honey bees had been confirmed in ten southern US states.

Africanized and European honey bees are cousins; they are of same species though different strains, and they share the basic characteristics. The Africanized honey bees' aggressive defensive behavior earned them the "killer bee" nickname. They are also more difficult to manage due to frequent swarming and high absconding rates. Beyond those negatives, however, Africanized bees exhibit more positive differences from their European cousins, such as resistant to *Varroa* mite, using more propolis, and adapting well to tropical zones. Since the introduction of Africanized honey bees in Mexico, honey production had dropped, which might have been attributed to beekeepers dropping out of the profession. Mexico's honey production has since recovered, and now, they prefer Africanized honey bees.

In the United States, managed honey bee colonies have steadily declined in the past 60 years from six million in 1947 to only 2.5 million in 2014. Starting in 2006, commercial beekeepers in the United States reported an average of 30% per winter losses as opposed to the historical rates of 10–15% colony losses. In the United States, where honey bees contribute billions of dollars in added value to the agriculture, these bee losses must be taken seriously. For many years, the commercial managed honey bee losses were due to Colony Collapse Disorder (CCD), where a specific set of symptoms led to catastrophic death of a colony. The trend was alarming, but according to the newest reports from the US Department of Agriculture, CCD was not among the major cause of winter losses in the last couple of years.

Many stressors are correlated with CCD, such as pesticides (insecticides, herbicides, fungicides), parasites, disease, and poor nutrition. Many scientists believe that CCD is caused by a combination of the above factors, where the compounding variables make it much harder to study.

There is no doubt about there is economic impact due to honey bee population decline, but how much of an impact? We know that humans will not all die in 4 years if bees disappear from the surface, because some of our most productive crops are wind-pollinated or self-pollinated. However, our food will contain less variety, cost more to produce and to purchase, and have less nutritional quality.

Beekeepers should follow best management practices to care for their bees: monitor colonies for any pest infestation and apply treatments at the best time, rotate treatment methods to prevent pests from developing of resistance, requeen if necessary, and use resistant-bred queens when possible. Since selective breeding programs are available, beekeepers may consider purchasing resistant-bred queens or even breeding themselves. Some of the potential breeding possibilities include breeding for *Varroa*-sensitive hygiene (VSH) trait, for the tropical hardiness and mite resistance of Africanized honey bees, and for cold weather and mite resistance of the Russian honey bee.

Everyone from individuals to governments should diligently contribute to protect and conserve the honey bees and other pollinators. The general public can grow bee-friendly flowering plants in their backyards and window sills; farmers can increase the habitat diversity in farmlands by planting native and nonnative, flower-rich herbaceous plants in appropriate areas, which will in turn help nearby crop fields; beekeepers can also improve the bee yards by creating or allowing nectar-rich wild flower areas on the premises, planting a variety of flowers that can provide nectar and pollen across honey bees' foraging seasons. Government departments can apply pollinator-friendly best practices on government-controlled lands and encourage its citizens to cooperate through incentives.

Besides increasing habitat diversity for bees, everyone who must use pesticides should follow the pesticide usage best practices. Pesticides have been shown to cause notable problems for honey bees and other pollinators even if the effects are not outright lethal; research is still ongoing. Best practices include but are not limited to the following: use approved least-toxic pesticides, follow product instructions, start with the lowest recommended dose, select appropriate timing including when bees are not active, manage pesticides drift through weather conditions, application method, equipment settings, and spray formulation. At the same time, governments are reviewing research and may control pesticide use to protect honey bees and all pollinators in general.

2 Pollinators and Pollination

Pollinators are animals that facilitate the reproductive cycle of over 75% of flowering plants, including most fruits, and vegetables. These animals include small mammals such as bats, birds, and many types of insects including the most well-known and accessible honey bee.

The reproductive cycle of flowering plants includes pollination, which is the transfer of pollen grains (male haploid gametophytes) to the female gametophytes, which contain the ovules. The pollen grains produce male gametes, which in turn fertilize the ovules; these fertilized ovules develop into plant seeds. The ovary in which seeds are contained may develop into fruit. The seeds and/or fruit are then disseminated by various methods to fertile land in which they may grow as new plants. These plants then supply significant resources to other organisms including humans: food, building materials, fibers, and so on.

To incorporate pollinators into their life cycle, these plants produce flowers that contain pollen and nectar, which are both sources of food for bees and other pollinating insects. Besides providing food, serving as shelter and nesting spots for their various pollinators, plants also produce resins. Resin is an important compound that honey bees specifically retrieve to produce propolis, which is used to fortify the hive, improve hygiene by preventing parasites and inhibiting fungi and bacteria, and mummify carcasses they cannot remove from the hive [1].

As the pollinator travels and gathers food and materials from these flowering plants, pollen grains stick to its body and are carried from flower to flower, fertilizing other plants of the same species along the way. Thus, pollinators and flowering plants have tightly integrated and mutually beneficial relationships [2].

Pollination, particularly that provided by insects, is essential to agriculture, which not only provides food to humans but also fibers, fuel, and feed to our domesticated animals that further provide sources for meat.

While there is a very wide variety of animal pollinators contributing to the ecosystem, most animal pollinators are insects, and within insects, most are bees. Bees consist of thousands of species but are broadly split between two basic categories for the purposes of study in agriculture and other industries of interest to humans: wild (native) bees and honey bees.

2.1 Wild Bees

Wild bees, also referred to as native bees for a given locale, are those bees not managed by humans, where management involves breeding and generally tending to the bees' basic needs such as providing shelter and supplemental food. Wild bees may be either social or solitary.

More than 90% of the world's 20,000 plus bee species are in fact solitary, which makes both management and research very challenging compared to the highly social nature of honey bees that live in structured colonies. A solitary bee is simply one that lives alone, where each nest is built and occupied by a single female with no caste or role hierarchy [3].

Bumblebees are social bees like honey bees, but their nest population numbers in the low hundreds, not the tens of thousands honey bees in a colony. Bumblebees are not as widely adopted into commercial apiculture (beekeeping), because they produce only small amounts of honey-like substance sufficient for their own consumption and are difficult and expensive to raise. Certain species are reared for commercial pollination in greenhouses, but most species of bumblebee are wild [4].

Roughly 4000 species of wild bee are native to the United States, and they are still credited with the majority of pollination activities with respect to native plants. For example, the imported honey bee either cannot or poorly pollinates tomato, eggplant, pumpkins, cherries, blueberries, and cranberries [5].

However, consistent and accurate studies for wild native bees, most of which are solitary, can be difficult to achieve. The accessibility of managed honeybee colonies means more data on their pollinator role and environmental effects upon them, particularly in close relation to agricultural production.

2.2 Honey Bees

Farmers manage only 11 of over 20,000 bee species worldwide, with the European honey bee (*Apis mellifera*) being the most commonly managed bee species [6].

Since honey bees are the primary subject of most pollinator-crop studies due to the close relationship between the beekeeping and agriculture industries, a basic understanding of their characteristics is necessary. Subspecies and hybrids exhibit variations in behavior and morphology, but all honey bees share the following general characteristics.

2.2.1 Honey Bee Colony Social Structure

The honey bee colony's social structure is particularly important when considering stressors that are transferred from individual to hive, such as infectious diseases and parasites that target concentrated populations of bees.

Honey bees are highly sociable insects. A honey bee colony consists of three types of adult bees: one queen, several drones, many workers, and brood (eggs, larvae, and pupae). All of them live in a hive constructed of wax comb containing many hexagonal cells; for managed hives, the comb is suspended within a frame, which can be plastic or wood. Within the cells, the bees store pollen and honey, and rear the brood (Table 1.1).

There is only one active queen bee per colony—a fertile female bee larger than other bees and whose main responsibility is to reproduce by laying eggs to increase and maintain colony size. The queen bee mates only once with several drones and remains fertile for her lifespan, which can be several years. There are different mechanisms to replace a queen if it dies, such as feeding a larva royal jelly and allowing it to develop into a virgin queen, or adopting a queen exiting another colony that already has a queen. Under managed conditions, beekeepers (apiarists) will commonly purchase a fertilized queen bee from a reputable source.

Drone bees are fertile male bees and number approximately 300–800 per colony; stingless and lacking the physiology to forage or build hive comb, the drone's sole purpose is to mate with a queen, and dies shortly after doing so.

Worker bees are the smallest and most numerous colony members, numbering approximately 20,000–80,000 bees per colony and constituting over 98% of its population. They are sterile, female, and are responsible for numerous duties that are split between two main worker roles: house bee or foraging field bee. House bees are responsible for hive upkeep including cleaning, brood feeding (as "nurse" worker bees), caring for the queen, building hive comb and food storage, and defense. Field bees are responsible for foraging, which is the retrieval of various resources (pollen, nectar, propolis, water). House bees are typically young worker

Table 1.1 Queen, drone, and worker bees [7]

	Queen	Drone	Worker
Sex	Female	Male	Female
Number	Typically one per colony	~300 to 800	~20,000 to 80,000 (about 98% of the colony population)
Fertility	Fertile	Fertile	Sterile
Stinger	Yes; only for fighting other queens	No	Yes; for colony defense. Dies after issuing a sting that pulls out the stinger apparatus
Body size	Generally larger than drone and worker when mature	Larger than worker	Smallest
Anatomy	No pollen-collecting apparatus	No pollen-collecting apparatus	Has pollen-collecting apparatus (pollen basket)
Responsibility	Mating and laying eggs to produce all the colony's offspring	Mate with a virgin queen from another colony; dies after successful mating	Hive upkeep, defense, foraging

bees, while field foragers are more mature worker bees. All worker bees have a sting and usually die after using it.

Flower nectar converted into honey is the bees' primary source of carbohydrates for energy. Pollen or "bee bread" is their primary source of protein, fatty acids, minerals, and vitamins, which are crucial for overall hive health and young bee development [8].

Besides collecting pollen, nectar, water, and resin while foraging, worker bees also produce "royal jelly" to raise a queen, secrete enzymes to ripen honey, and produce wax for hive comb construction. One foraging worker bee makes a dozen or more trips in a day, visiting several thousand flowers in a range of 2–5 miles away from the hive. They typically limit themselves to one plant species per trip, which aids in the pollination process. A foraging bee can return to its colony bearing a pollen load weighing nearly 35% of its own body weight. The pollen gathered by worker bee "pollen baskets" located on their legs is also a food supplement used by humans and some other animals [7, 9].

2.2.2 Honey Bee Reproduction

Individual

Worker bees build hexagonal comb cells using wax produced from their wax glands, and these cells serve as food storage for honey and pollen as well as incubation for the bee brood. The "brood" consists of eggs, larvae, and pupae, which are the bees' early developmental stages.

Sometime after her mating flight and being fertilized by multiple drones, the queen bee lays one egg in each cell; in the spring and early summer, she may lay up to 1500 eggs per day. Fertilized eggs become female worker bees (sterile), while unfertilized eggs become male drones (fertile).

In 3 days, the egg hatches into a larva. Inside its beeswax cell, the larva is fed by the "nurse" worker bees, and after a few days, the worker bees seal the cell with a wax "cap." After being capped, the larva enters the pupa or transformation stage, where its grub-like form changes into an adult bee. The developed adult bee emerges from the cell 7.5–14.5 days after the capping, depending on its caste [8].

Swarming

Swarming, essentially colony-level reproduction, is the process of forming a new colony by leaving the parent colony and nesting in a new location. When environmental variables are favorable and food sources plentiful, a colony's population will increase to a certain point that causes crowding within the hive. At this point, the bees will begin to raise a new queen. As the new queen reaches maturity, the original queen flies away with a swarm consisting of at least half the existing worker bees and some of the drones, while the new reared queen stays with the parent colony. When the new queen matures, she will take mating flights and begin to lay eggs to increase the bee population as most had left with the swarm.

Swarms look intimidating but are usually harmless and rarely sting, because the bees do not yet have brood, honey, or hive to defend. The exiting swarm will land somewhere nearby to rest, and the worker bees will cluster around the queen to protect her while some scout bees leave to search for another suitable home. Once a home location is found, the swarm will create a hive and continue their activities in foraging and raising bees. Under ideal conditions, European honey bee colonies swarm approximately once or twice a year [10].

2.2.3 Honey Bee Communication

Pheromones

The honey bee has two primary modes of communicating with other members of its colony: pheromones and dances, particularly the "waggle" dance. Pheromones are chemicals secreted from honey bee glands that affect behavior in other bees and thus affect all aspects of colony life. The waggle dance is a physical activity done to convey spatial information of a resource location.

Pheromones are transmitted by direct contact as liquid or vapor and received by bees' antennae and other body parts to trigger behavioral or physiological responses, usually in the same species [11]. Pheromones are secreted by all colony members from queen, drone, worker bee, to brood (particularly the larvae), and allow communication among all castes. They are involved in all aspects of colony life including reproduction (queen mating and swarming), brood development, defense, foraging, building hive comb, and other activities [12].

Some glands and pheromones are caste-specific. There are two types of pheromone effects: releaser, which temporarily affects the recipient's behavior, and primer, which has long-term physiological effects. The queen signal and brood pheromones are of the primer type, while most worker bee pheromones are considered the releaser type.

Queen bee pheromone (queen mandibular pheromone) has different effects on different bee castes. For example, it serves as a sexual attractant for drones during the mating flight while also serving to attract the queen retinue, which is a group of worker bees whose role is to attend to the queen. The pheromone is responsible for inhibiting additional queen rearing, suppressing fertility in worker bees, keeping a swarming bee cluster together, stimulating worker bee activity around the hive, and generally calms a swarm.

Drone pheromones are concentrated upon sexual activities, such as attracting other flying drones to aggregate at sites suitable for mating with a virgin queen [13].

Brood pheromones secreted by larval salivary glands and serve to regulate brood development and care by chemically communicating needs to nurse worker bees. Along with queen pheromones, brood pheromones suppress worker ovarian development, since fertile worker bees do not work as much as sterile. Finally, the level of brood pheromones can modulate behavioral maturation in worker bees: a low level decreases the adult bee foraging age, promoting a larger proportion of worker bees to become foragers; a high level of brood pheromone increases worker foraging age, stimulating young adult workers to remain as nurse bees for an extended period of time [14].

Worker honey bee pheromones cover a wide range of functions. Depending on the age and role differentiation of the worker bee, glands develop at different times or produce different pheromones depending on the situation. For example, wax glands develop sooner and are more active in young worker bees for building comb, while alarm pheromone production rises in older guard and forager bees. The glands responsible for producing pheromone that suppresses worker bee fertility also produce alarm pheromone when the worker bee becomes a forager [15].

Honey Bee Dances

All of the known species and subspecies of honey bee exhibit dancing behavior, but the form and details of execution vary among species [16].

The following describes *Apis mellifera*, as it is in the most widely managed honey bee species. There are several known honey bee dances, including the waggle dance, round dance, tremble dance, and grooming dance. Each dance conveys information, but the use of said information may be context-dependent [17].

The waggle and round dances are used by forager bees to communicate foraging locations. The round dance is performed by a returning scout or forager when it wishes to communicate a food source less than about 35 yards away from the hive; the bee will move in circles alternately to the left and right, without indicating specific direction, but it will share the scent of the food source [18].

When a resource is more than 35 yards away, the honey bee will perform the waggle dance instead; this resource may be food, water, or even a new nest site. This is a more complex dance that communicates direction relative to the hive, distance, and odor of the target resource if applicable [19, 20].

The waggle dance is usually performed on the vertical surface of the hive comb. The dancing bee first moves forward for a certain distance along the vertical line of the comb, and this vertical line serves as the reference base for the direction. Then the bee moves back to the starting point and begins her dance pattern. Each dance involves running through a figure-eight pattern with one straight phase and two half circle return phases; the dance move pattern is then repeated. On the straight stretch phase, the bee “waggles.” The angle between the straight stretch and the vertical line is the angle of the target sources relative to the sun. If experiencing a long delay and the sun has moved, the dancing bee adjusts the angle accordingly. The distance to the target resource is expressed by the duration of the straight waggle phase. One second is approximately for 1 km of distance. The time taken to complete the waggle phase is directly related to the distance, and the speed of the waggle is inversely related to the actual distance [19].

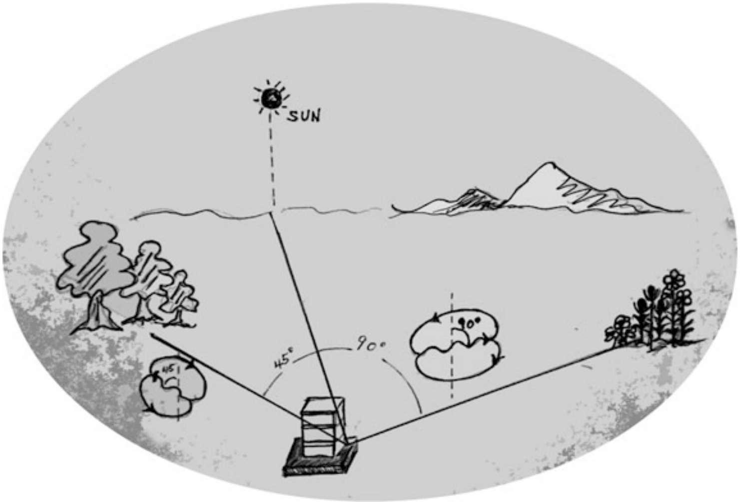

Fig. 1.1 Honey bee waggle dance [19]

The speed or the frequency of the repeating dance pattern performed is an indication of the quality of the resource; the higher the speed of the dance means the better the quality of the resource. When dance repetition is low or reduced, it indicates potential risk. If a dead bee is found at a potential foraging site, for example, returning foragers and scouts perform fewer waggle dances relative to that location [21, 22] (Fig. 1.1).

2.2.4 European Honey Bees

The honey bee as we know it was not native to the Americas; they were, in fact, imported from Europe during colonial times in the 1600s. *Apis mellifera* was instead native to Europe, Asia, and Africa, and evolved into different subspecies by geography throughout Africa and Eurasia. These honey bees are referred to as European or western honey bees [23]. The majority of available pollination information is derived from European honey bee data for this reason.

Most crops grown in the United States are not native to the Americas either. Both the crops and honey bees evolved in other parts of the world and were brought to United States by European settlers. Today, more than 90 commercially produced crops in the United States rely on bee pollination [8].

Honey bee population numbers and temporal activity patterns are easily assessed by visual inspection. Physically managed hives can produce important information on hive conditions and activity, the timing of flowering and nectar access, and details about the interaction between bees and the environment [24].

It is important to note at this point that "feral" honey bees are not considered the same as wild bees, which are native to the locale. Rather, feral honey bees are those that escape apiaries and establish colonies away from human management, but are still an alien species.

2.2.5 Africanized Honey Bee

All subspecies of *Apis mellifera* can interbreed or hybridize. The Africanized honey bee is a hybrid of the European honey bee and African bee, which are two separate strains of the same *Apis mellifera* species. Africanized bees acquired the appellation "killer bee" due to their highly aggressive defense behavior, which can often result in serious injury and death for humans and other animals [25].

Pure African honey bees, *Apis mellifera scutellata,* were imported into São Paulo, Brazil, in 1956. The intention was to breed the African honey bees, which were better adapted to a tropical environment, with European honey bees in order to improve country's honey production. Just 1 year later in 1957, 26 African queen bees were accidentally released or escaped from the managed facility into the wild. The cross-bred descendants of these African and European honey bees quickly established a large feral population of Africanized honey bees. This event unintentionally demonstrated the Africanized honey bee's superior adaptation to the tropical environment. In just over four decades, these wild AHB migrated to most of the tropical and subtropical area of America, from South to Central then to North America.

The first permanent colonies arrived in City of Hidalgo, Texas, from Mexico was in 1990; the first documented AHB case in the State of Florida near Tampa was 2001; by 2003, AHB had spread to Tampa and throughout of the Florida state. By July 2009, AHBs have been confirmed in ten southern United States: Texas, New Mexico, Arizona, California, Nevada, Utah, Louisiana, Oklahoma, Arkansas, and Florida [26] (Fig. 1.2).

Africanized Honey Bee Characteristics Summary

Beyond the very aggressive hive defense behavior, Africanized bees exhibit additional differences from their European cousins (Table 1.2).

Heightened Defensiveness

The Africanized honey bee is notorious for highly aggressive defense behavior. However, they do not randomly seek out victims to attack. They are very sensitive to alarm pheromone and produce much more of it than European honey bees [31].

They ardently guard and protect their hives within a wide range of at least 30 m. Africanized bees also have a low threshold for disturbance; direct hive disturbance is

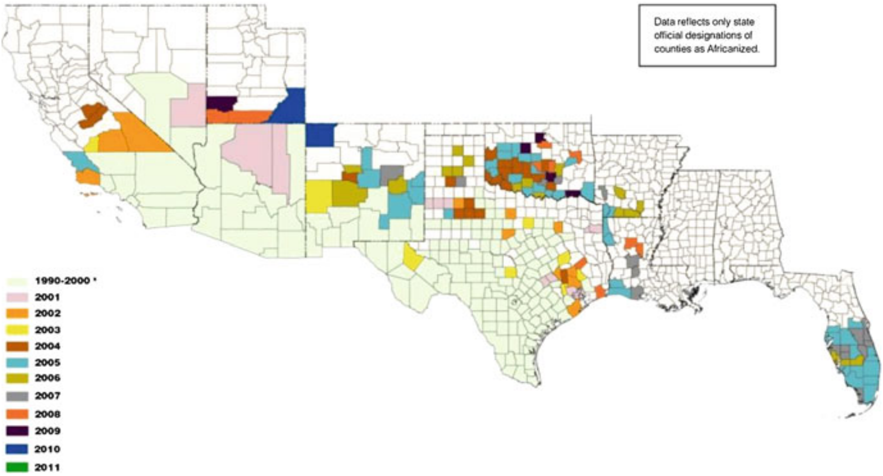

Fig. 1.2 Spread of Africanized honey bees in the southern United States to 2011. (Source: USDA [27])

Table 1.2 Differences between European and Africanized honey bees [26, 28–30]

	European	Africanized
Defensive behavior	May send 10–20 guard bees up to 20 feet away from hive. 10–15 minutes to calm down. Calmed down by smoke. Disturbance may result in 10–20 stings.	May send hundreds of guard bees up to 120 feet away from hive. Hours to calm down or until sunset. Disturbance may result in 100–1000 stings.
Climate adaptation	Temperate zones.	Tropical zones.
Swarm behavior	Swarm 1–2 times per year, only if crowded or to make new nest. Large swarms requiring larger volume sites.	Can swarm 10+ times per year. Smaller swarms requiring smaller nest sites.
Abscond (nest abandonment)	Rare.	Often, relocating in times of stress (shortage of resources, infected nest, etc.).
Nest characteristics	Larger space (~38 liters).	Smaller cavities (~3–19 liters).
Survival strategy	Expend energy in producing and storing honey and pollen to prepare for resource shortage (e.g., overwintering).	Use energy and resources in producing large numbers of progeny and generating many reproductive swarms.
Varroa susceptibility	Susceptible to *Varroa* mites, which shuts down the bees immune system.	Resistant to *Varroa* mites.
Age-based worker behavior	Start foraging at older ages and harvest less pollen and more concentrated nectar.	Start foraging at young ages and harvest resources with low concentrations of sucrose that include water, pollen, and low concentration of nectar.
Physical differences (usually only distinguishable by tool)	Slightly larger.	Slightly smaller.