CLINICAL PARASITOLOGY

9TH EDITION

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Preface

Originally, and through its several editions, this volume was intended to be a handbook source of information for physicians and for graduate and postgraduate students in human parasitology. In the preparation of the new edition, our aim was to retain the format and general purpose of Craig and Faust's *Clinical Parasitology* as stated in the preface of the first edition: "to set down . . . the essential facts concerning the animal parasites of man and the diseases they produce, together with approved methods of diagnosis, treatment and control." In the preface to the eighth edition, attention was called to the expansion of scientific knowledge since the appearance of the first edition 33 years earlier, and to the difficulty of preparing a new edition of acceptable size, yet encompassing the greatly expanded subject. The past decade has not only produced scientific advances at an accelerated pace, but it has witnessed extraordinary changes in the way of life around the globe.

Rapid and increasingly frequent travel is usually identified as a major factor in bringing patients with exotic parasitic infections to the offices of European and North American physicians. Perhaps more important is the easy availability of intercontinental travel, which permits large numbers of young people with casual or cultist attitudes toward disease prevention to wander about the world. Drug abuse by the intravenous route is now commonplace in all segments of society and may be expected to be involved increasingly in the transmission of parasitic infections of the blood. A new permissiveness in the sexual mores has resulted in remarkable changes in the epidemiology of certain parasitic infections. Giardiasis and amebiasis are now in some cities more commonly transmitted sexually than by contaminated water or food. The mysterious disorder of the immune mechanisms known as the acquired immune deficiency syndrome (AIDS), first noted in male homosexuals, but now recognized in ever more groups, is responsible for outbreaks of pneumocystosis, formerly a relatively rare condition. One of the most striking changes in the United States, Canada, and some European countries has been the influx of large numbers of refugees and immigrants from less developed countries. Many of these people have parasitic infections that should be detected and eliminated if possible. Many continue the food and sanitation practices that are traditional in their native cultures and that may result in new zoonotic infections in the new environment.

There has been a tremendous multiplication of chemotherapeutic agents that give promise of providing safe, effective treatment for many of the infections that only a decade ago had no effective therapy or were treated with relatively toxic drugs. At the same time, legitimate governmental concern over the safety and efficacy of drugs has led to regulations that limit the availability of useful drugs. The risk of lawsuit for damages as much as concern for the patient's safety has forced the practicing physician to revise his office routine and to modify his attitudes toward drug selection. Carcinogenicity, teratogenicity, and mutagenicity of drugs were hardly considered ten years ago. Now they must be explained to the patient in order that he may give "informed consent" for treatment. We have endeavored to provide the user of this book with up-to-date information regarding these changes in a fashion sufficiently concise that the book is not appreciably increased in size.

Recently, numerous species known only as parasites of animals have become recognized as occasional parasites of man, and thus it became necessary to expand the number of zoonotic species to be described and discussed. Freeliving animals that colonize and cause serious disease in man, the amphizoic forms, have assumed new importance. The amphizoic amebae, *Naegleria* and *Acanthamoeba* species, only briefly mentioned in the previous edition, now constitute a separate chapter. To include the additional zoonotic and amphizoic agents of human disease, and to add essential new information about familiar forms, without expanding the volume, required rewriting parts of all chapters and the greater part of some. Many of the old illustrations were discarded or replaced and new ones were added. Numerous references are cited, both to sources of additional information and to reports of findings that are subject to different interpretations.

Studies on parasites and parasitic diseases have moved more actively into the fields of biochemistry, immunology, and electron microscopy. Although basic information derived from these newer studies has been incorporated in some of the descriptions, our chief aim has been to draw from the massive and widely scattered literature the essential facts about the individual parasites needed by workers in those fields who would apply their specialized skills, knowledge, and instruments in research efforts toward a better understanding of parasitism as a biological phenomenon and its relation to human disease.

The two senior authors have collaborated on all subjects considered in this volume. The junior author assumed primary resonsibility for the section on arthropods and collaborated in preparing the material on arthropod vectors of malaria, filariasis, and some other infections. Work on the revision began in January 1979 and manuscript copy was completed in May 1982. Additions and further minor revisions were made in galley proof up to April 1983.

For advice and assistance we are indebted to departmental colleagues and others. For permission to use published or original illustrations we are indebted to numerous publishers, authors, and others, all of whom are acknowledged individually in the legends. For assistance in obtaining essential literature and in manuscript preparation and editing, especial thanks are due Miss Helen Day and Mrs. Ena Castillo. We acknowledge with special thanks also the guidance and cooperation of the publisher, Lea & Febiger.

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General Information

Chapter 1

The Parasite and Its Environment

All animal and plant forms originated and developed as free-living organisms that were obliged to compete with others for their existence. Only those that developed satisfactory adjustments and adaptations were able to survive. Among this group were many species in different phyla of the Animal and Plant Kingdoms that came to depend on their associates for shelter and food. In some instances, the remarkable adaptations suggest that this interrelationship has existed for a long time, probably thousands of years. Other groups of parasites appear to have more recently acquired a parasitic mode of life, and a few of these have not yet become irreversibly committed to parasitism. Still others are only now developing the earliest adaptations to parasitism.

DEFINITION OF TERMS

Parasitology is the area of biology concerned with the phenomenon of dependence of one living organism on another. The *parasite* lives on or in its *host*, which is usually a larger organism that provides physical protection and nourishment. If the parasite derives benefit without reciprocating and without injury to the host, the relationship is referred to as *commensalism;* if the relationship is beneficial to both associates, it is *mutualism*. Close association of the two is *symbiosis*. Hosts that transmit parasites to man are *vectors*. Those that are essential in the life cycle are *biologic vectors;* those that are not essential are *phoretic* or *mechanical vectors*. *Predators,* which attack and kill animals in order to obtain food, usually feed on smaller or weaker animals who are their *prey*.

Many animals that are related to parasitic species are free-living. Among the parasitic forms, some depend on plants as their hosts and are frequently of great economic importance. Others live on or within invertebrate animals, while still others parasitize vertebrate hosts. *Clinical parasitology* is concerned primarily with the animal parasites of man and their medical significance, as well as their importance in human communities.

HOST-PARASITE INTERRELATIONSHIPS

In a majority of instances, only one host is required for a parasite to carry on its life cycle. There may be relatively "fast" host specificity for a particular species of parasite, as occurs with the pinworm of man *(Enterobius vermicularis)* and the human body louse *(Pediculus humanus humanus)*, for example. Certain anopheline mosquitoes have a preference for human blood when it is available—i.e., they are *anthropophilic*. Other parasites are less discriminating, and man constitutes only one of several satisfactory hosts. The Chinese liver fluke (*Clonorchis sinensis*), the Oriental blood fluke (*Schistosoma japonicum*), and the trichina worm (*Trichinella spiralis*) are representative of this group. In many instances, man is only incidentally involved as a host, while domestic or wild animals serve as *reservoirs* of the parasite.

Susceptibility to a parasite by several host species introduces the concept of *zoonosis*, which literally means "disease of animals," but today the term is employed for those diseases of animals that are transmissible to man. Hoare (1962) credits Virchow with the invention of the term. Several classifications of zoonoses have been proposed. For example, if the parasitosis is common to man and reservoir hosts, it may be referred to as a *euzoonosis;* if man is an infrequent (hence, incidental) host, it is a *parazoonosis*. Koegel (1951) proposed the term "anthropozoonosis" for infections acquired by man from other vertebrates; e.g., those infections acquired directly, as in the case of trichinosis or cysticercosis, or the large number of infections transmitted by arthropod and molluscan intermediate hosts. Diseases primarily of human origin that may be acquired by other vertebrates are *zooanthroponoses* (Wagener, 1957), and diseases common to man and other vertebrates are *amphixenoses* (Nelson, 1960).

Hoare (1962) adds that zoonoses constitute "a chapter in the natural history of parasitic infections which concerns the ecological and evolutionary aspects of the host-parasite relations . . . has led to intensive studies of the ecological conditions under which infections are maintained among wild animal hosts and vectors." Garnham (1959) stated that the zoonotic process is dynamic and that the best zoonotic species are the least differentiated ones. Modern civilization tends to disrupt the natural course of many euzoonoses so that man becomes involved in their cycles, at times with disastrous consequences (van der Hoeden, 1964; Hubbert et al., 1975).

Organisms that cannot exist without a host are *obligate parasites*. Other organisms that—under favorable circumstances—may live either a parasitic or free-living existence are called *facultative* or "opportunist" parasites. For example, in some circumstances, *Micronema* and certain free-living amebae (*Naegleria* and *Acanthamoeba*) may invade and colonize in the human brain or other sites; Page (1974) coined the term "amphizoic" for such organisms. In addition, some free-living animals or organisms that parasitize other hosts, having merely passed through the intestine, are recovered in a living or dead state from human feces; they are referred to as *spurious* parasites of man.

In microbiology, the relationship of the parasite to its host is designated as an *infection*. This is also the appropriate designation for all animal species that are endoparasites, whereas those that are *ectoparasites* (those that are attached to the skin or that temporarily invade the superficial tissues of the host's body) produce an *infestation*. This distinction is employed irrespective of the size of the invader, but infestation of the host is most frequently applied to species of arthropods. In the more limited sense, *parasitosis* is the state of infection or infestation with an animal parasite.

Some animal parasites of man are normally harmless commensals (Baer, 1951; Henry, 1966). Notable among these are several intestinal amebae and flagellates. On the other hand, a great majority of the animal parasites are harmful, frequently causing local and systemic damage of one type or another; these species are called *pathogens*.

When an individual harboring a parasite is reinfected with the same species of parasite, this is *superinfection*. In case the infected person is his own direct source of the re-exposure, it is *autoinfection*, which may be external (namely, perianal or anus-to-mouth via fingers) or internal in the mode of infection.

SOURCES OF EXPOSURE TO INFECTION OR INFESTATION

Exposure may occur from one or more of the following sources: (1) contaminated soil or water; (2) food containing the immature infective stage of the parasite; (3) a blood-sucking insect; (4) a domestic or wild animal harboring the parasite; (5) another person, his clothing, bedding, or the immediate environment that he has contaminated; or (6) one's self. Each of these sources will be briefly illustrated.

Soil polluted with human excreta is commonly responsible for exposure to infection with *Ascaris lumbricoides*, *Trichuris trichiura*, human hookworms, and *Strongyloides stercoralis*. Water may contain viable cysts of parasitic amebae, intestinal flagellates, *Taenia solium* eggs, and the infective cercarial stage of the human blood flukes. Freshwater fishes constitute the source for fish tapeworm (*Diphyllobothrium latum*), as well as for several types of intestinal and liver flukes; crabs and crayfishes are sources for the Oriental lung fluke; raw pork is the source for *Trichinella spiralis* and *Taenia solium*; beef is the source for *Taenia saginata*; buffalo nuts (*Trapa* spp.) are the source for the giant intestinal fluke (*Fasciolopsis buski*); and watercress (*Nasturtium officinale*) is the source for the sheep liver fluke (*Fasciola hepatica*). Blood-sucking arthropods transmit malaria parasites, leishmanias, trypanosomes, filariae, viruses, rickettsiae, bacteria, and spirochetes. Dogs are the direct source for human infection with the hydatid cyst of *Echinococcus granulosus*, as well as for visceral larva migrans due to *Toxocara canis*, while herbivorous animals commonly constitute the source for human infection with *Trichostrongylus* spp. Other human beings are directly responsible for all or a considerable amount of infection with the pathogenic ameba (*Entamoeba histolytica*), the pinworm (*Enterobius vermicularis*), and the dwarf tapeworm (*Hymenolepis nana*). Autoinfection accounts for some of these parasitoses and for some reinfections with *Strongyloides stercoralis*.

PORTAL OF ENTRY INTO THE BODY

In the case of internal parasites, the most common portal of invasion is the mouth. This is the entrance for the intestinal protozoa (for most species in the encysted stage); the common roundworms *Ascaris lumbricoides, Trichuris trichiura* and *Enterobius vermicularis* and the dwarf tapeworm *Hymenolepis nana* (all in the fully embryonated egg stage); *Trichostrongylus* spp. as a free-living infective larva; and *Trichinella spiralis, Taenia solium, T. saginata, Diphyllobothrium latum*, intestinal flukes and the lung fluke, from eating food containing the mature larval stages of these worms.

A few important roundworms—namely, species of hookworms and *Strongyloides*—actively enter the body from the soil via the skin, as do the blood flukes (*Schistosoma* spp.) from fresh water. A large number of parasites that have a required developmental stage in blood-sucking arthropods are introduced percutaneously when the arthropod punctures the skin to feed. Among these parasites are the agents of malaria, the leishmanias, trypanosomes, filariae, many viruses and rickettsiae, and a few species of bacteria and spirochetes.

Other methods of transmission include the following: (1) inhalation of air-borne eggs of *Enterobius vermicularis* into the posterior pharynx; (2) transplacental (congenital) infection with *Toxoplasma gondii*, and occasionally with malaria parasites, blood flukes and others (Loke, 1982); (3) transmammary (milk) infection with species of *Strongyloides, Ancylostoma*, and certain trematodes (Miller, 1981); and (4) by sexual intercourse, in the case of *Trichomonas vaginalis*.

BIOLOGIC INCUBATION PERIOD

Exposure vs. Infection. Exposure to infection is the act or process of inoculation, whereas *infection* connotes a "take," whereby the infective agent becomes established in the host. Often the term "infection" is employed carelessly when the concept "inoculation" is intended. For example, a person may be exposed by ingesting cysts of *Entamoeba histolytica* without colonization of the ameba, so that no infection is produced.

Development of the Infection. Once the successful parasite has entered the body of the host, characteristically it is carried or actively migrates to a location where it matures and produces progeny. This may be a relatively simple procedure, or it may be lengthy and complicated. For example, for *Entamoeba histolytica*, it consists of excystation of the protoplast in the lumen of the ileum and division into as many small metacystic trophozoites as there were nuclei in the encysted stage, then passive carriage in the fecal stream through the ileocecal sphincter into the large intestine, lodgement in the glandular crypt, growth to normal size, and multiplication by asexual binary division. Similarly, for fully embryonated eggs of *Trichuris trichiura* and *Enterobius vermicularis*, it consists of hatching in the duodenum, migration of the larva down to the cecal level, attachment to the mucosa, and development to the adult stage, which is followed by the production of eggs of the new generation.

In the case of *Ascaris lumbricoides*, the ingested egg hatches in the duodenum. The emerging larva enters the mucosa and migrates via blood vessels to the lungs; then, after intrinsic development in the tissues, it breaks out into the air sacs and passes up the respiratory tree to the epiglottis, passes over into the digestive tract, and is carried to the small intestine, where it develops into the adult form. Hookworms and *Strongyloides stercoralis*, which actively invade the skin, are carried in the blood stream to the lungs, after which their course of migration parallels that of *Ascaris*.

Organisms that are introduced in the encysted larval stage in food characteristically become freed of their cyst wall or capsule in the duodenum. Intestinal helminths soon become attached to the mucosa, usually in the upper or middle levels of the small intestine, where they mature; inhabitants of the bile ducts enter via the ampulla of Vater (e.g., *Clonorchis sinensis*) or utilize a more indirect route (e.g., *Fasciola hepatica*); and the lung fluke *Paragonimus westermani* takes a devious route through tissues and body cavities before arriving at its destination near a bronchiole.

The blood flukes (*Schistosoma* spp.), after actively invading the skin, burrow to the cutaneous lymphatics and blood vessels. Once they have entered the blood stream, they are carried to the lungs, where they develop for several days before migrating to the liver. They grow in the liver and, on reaching sexual maturity, mate and migrate in copula to the smaller mesenteric venules (*S. japonicum* or *S. mansoni*), or via the mesenteric and rectal venules into the vesical venules (*S. haematobium*).

Malaria parasites, when introduced into human skin by an anopheline mosquito, are rapidly carried in the blood stream, from which they disappear in about 30 minutes. Later, after 2 or 3 days, they are found in the liver, where they undergo asexual multiplication in parenchyma cells before being discharged into the blood to initiate infection in the red blood cells. Trypanosomes may rapidly multiply in circulating blood (*Trypanosoma gambiense*) or may develop as intracellular parasites in macrophages near the site of inoculation or in the viscera (*Trypanosoma cruzi*). Species of *Leishmania* invariably colonize intracellularly in the reticuloendothelial system.

The filaria worms, once introduced as filariform larvae into the skin by the infected insect, enter lymphatic vessels in which the immature worms develop for several weeks or months, finally reaching maturity in various sites depending on the species of filaria; for example, *Wuchereria bancrofti* and *Brugia malayi* inhabit the lymphatic system, and *Loa loa* and *Onchocerca volvulus* inhabit the subcutaneous tissues.

End of the Biologic Incubation Period. Biologic incubation is terminated as soon as the parasites or their products can be demonstrated in the feces or other excreta or in the circulating blood (*parasitemia*), by aspiration, biopsy, or other diagnostic procedure. The biologic incubation period, also referred to as the *prepatent period*, varies from 1 or more days to weeks or months, depending on the particular species of parasite and its ability to develop in the particular host. *Biologic incubation* is related to the development of the parasite; *clinical incubation* refers to the interval between exposure and the earliest evidence of symptoms produced as a result of the infection (or infestation).

ENVIRONMENT AND METABOLISM OF PARASITES

The habitats of parasites are extremely varied. Among the parasites of man, there are examples of protozoa, helminths, and arthropods that normally inhabit the intestine, liver, lungs, muscles, brain, blood, and lymphatic tissues. Many species of parasites have complicated life cycles involving developmental stages that live in soil or water, or use various kinds of intermediate hosts, including invertebrates and vertebrates and cold and warm-blooded animals. In such varied environments, parasites have become adapted to using or tolerating widely differing oxygen, carbon dioxide, and hydrogen ion concentrations and temperatures, and their nutritional requirements are varied, as are their means of obtaining and utilizing the nutrients required for growth, motility, and reproduction. Current knowledge of the biochemistry and physiology of parasitic protozoa and helminths is reviewed in a recent treatise by von Brand (1979), who was the recognized founder and leader in the field of parasite biochemistry for 40 years. In their evolutionary adaptations, parasites have found ways to deal with the immune reactions of their hosts and to induce physical and physiologic host changes that are advantageous to themselves and tolerated by their hosts. The immunology of parasitic infections now constitutes a major subdiscipline of parasitology (Cohen and Sadun, 1976; Miller et al., 1977; Warren et al., 1977).

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Chapter 2

Epidemiology and Distribution of Diseases Caused by Animal Parasites

Epidemiology is the body of knowledge that concerns disease in human populations or communities rather than in individuals. Jungblut (1935) states, "In its widest definition the term epidemiology may be understood to include the study of the manifestations of any disease which happens to attack groups of individuals at any time." Maxcy (1956) refers to the subject as "that field of medical science which is concerned with the relationships of the various factors and conditions which determine frequencies and distributions of an infectious process, a disease, or a physiological state in a human community." Thus, epidemiology as a branch of medicine not only incorporates data in the area of infectious diseases in population groups, but also those resulting from anatomical deformities, genetic constitution, metabolic dysfunction, malnutrition, neoplasms, occupational pursuits, and the process of aging.

In spite of this broad concept, until recent decades the mass of epidemiologic information has accumulated mostly from a study of *communicable diseases*. Yet it is frequently difficult, except in epidemics, to isolate the effects of an infectious agent in a community from other disease entities that are almost invariably operating simultaneously.

When disease in the human population maintains a relatively steady, moderate level, it is said to be *endemic;* if the prevalence is high, it is *hyperendemic*; if there is a sharp rise in the incidence or an outbreak of considerable intensity occurs, it is considered to be *epidemic*; and if it appears only occasionally in one or at most a few members of a community, it is reported as *sporadic*. Endemicity is commonly associated with a certain degree of tolerance to the pathogen; epidemicity typically results from introduction of an agent or a new strain into a community that is essentially nonimmune, the sudden development of enhanced pathogenicity by the infectious agent, or the markedly increased prevalence of a vector. For example, certain communicable diseases, such as smallpox and measles, were endemic in Europe at the time Columbus discovered America, but when the American Indian population was exposed, these diseases became epidemic in the Americas, with decimating effect. At times communicable diseases have been disseminated over extensive areas of the world, producing *pandemics*. Notable among these have been influenza, plague, and cholera.

The term referring to the knowledge of the frequency of disease in animal communities is "epizootiology." Moderate prevalence of a disease in animals is designated as *enzootic*, a sudden outbreak as *epizootic*, and wide dissemination as *panzootic*.

EPIDEMIOLOGIC METHODS

Methods of epidemiologic study are applicable irrespective of the type of disease-producing agent. Useful information may be obtained by two principal approaches. First of all, observation and study of an individual patient by a competent investigator may provide accurate clues to the way a particular disease has been acquired. This can lead to an epidemiologic study to determine the extent and prevalence of the disease, the nature of vectors or other factors involved in transmission in the community in which the patient contracted it, and the chances of its dissemination. Second, one may use the statistical approach, which utilizes vital statistics accumulated by local, state, and national government health agencies that incorporate morbidity data on infectious diseases.

In 1923 the Health Organization of the League of Nations came into existence; it was assigned the responsibility of notifying of epidemic diseases, providing consultation service, standardizing biologicals, drugs, health education, and training and research in the field of infectious and epidemic diseases. In 1948, 3 years after the United Nations came into existence, the World Health Organization (WHO) was established as the special agency of the United Nations. WHO took over the functions of the Health Organization of the League of Nations.

Biostatistical Methods. Mortality rates are usually expressed in deaths per 100,000 per year. Morbidity rates are commonly reported as cases of notifiable diseases per 1000 per year. The crude rates require adjustment to account for variables in the community, such as racial composition, age, sex, occupation, hospitalized or nonhospitalized persons, and any other factors that may reasonably affect the data. Moreover, in order to be significant, the statistics must have been obtained from a sufficient sampling of the population that it is intended to represent. The information derived from the adjusted data of a representative sample requires treatment to determine the mean, standard deviation and standard error of the mean before it is possible to judge the reliability of the data in making generalizations about the population under investigation. Even then it represents a group and is not applicable to a particular individual of the group sampled or to another group in the same community or elsewhere. Nevertheless, vital statistics, when they are properly accumulated and analyzed, may be compared with similar data from other areas to determine whether or not there is a significant correlation; likewise, when accumulated year by year, such data provide valuable evidence as to trends, including epidemic cycles, and increases and declines in the rates.

EPIDEMIOLOGIC INVESTIGATION OF PARASITOSES

Basic epidemiologic information is available on practically all important parasitic infections that affect man. This information includes the stage of the parasite that is discharged from the human body (or reservoir host); the stage of the parasite that is available for an arthropod to pick up while feeding on the skin; extrinsic development of the parasite, whether on the soil, in water, or in the body of required alternate host (or hosts); and the way in which each parasite gains entry into the human body. Moreover, there is relatively good information concerning the geographic distribution of these infections, their frequency in different population groups, their tendency to endemicity, hyperendemicity, epidemicity, or sporadic occurrence in different areas and, in some infections, trends or cycles of increase or decrease. Relatively abundant data have been accumulated for amebiasis, malaria, leishmaniasis, African trypanosomiasis, Chagas' disease, trichinosis, hookworm disease, ascariasis, enterobiasis, Bancroft's filariasis, onchocerciasis, and schistosomiasis.

In undertaking an investigation on the prevalence of malaria or intestinal parasites in a community, a sufficient number of individuals must be examined to constitute a representative sample of the population. Frequently, school children are surveyed, and while the results obtained may be dependable insofar as this age group is concerned, they are not necessarily referable to older age groups. However, children found infected in a school-age survey may be utilized as leads for follow-up studies on parasite frequency in each child's family. In this way, it may be possible to obtain significant information distinguishing between the environmental sanitation and personal hygiene responsible for exposure to the infections.

Essential epidemiologic data have been contributed by medical entomologists and biologists for the parasitoses of man; arthropod-transmitted viral diseases, such as yellow fever, dengue, and several encephalitides; the rickettsioses, plague, tularemia, and relapsing fevers.

The epidemiologic aspects of each important disease considered in this text will be presented in chapters on the etiologic agents or vectors.

GEOGRAPHIC DISTRIBUTION OF HUMAN PARASITOSES

Geographical Areas of the Earth. Maps of the world usually divide the land and sea into a central band called the "Tropics," two broad bands, one on either side of the Tropics, called the "Temperate Zones," and a cap around each of the poles, called the "Arctic" and "Antarctic Regions." For general purposes, these geographic delimitations are relatively satisfactory, but they are not accurate insofar as climate and the existence of plant and animal life are concerned. Astronomically and geographically, the Tropics lie between two charted circles engirdling the globe, one 23°28′ North and one 23°28′ South of the Equator. The former is the Tropic of Cancer, and the latter is the Tropic of Capricorn. Similarly, the Arctic and Antarctic Circles lie 23°28′ from the North and South Poles, respectively.

The Tropics may be defined as the warm band engirdling the globe in which the mean temperature *for the coldest month of the year* is never less than 20° C (68° F), while the subtropical zones are those on either side of the Tropics in which the mean temperature *for the entire year* is never lower than 20° C (68° F). The plotted lines (frequently referred to as "Supan's lines") delimiting these areas, and their divergence from the Tropic of Cancer and Tropic of Capricorn, respectively, are shown on the accompanying map (Fig. 2–1). The differences between the geographic and the isothermal boundaries of the several regions of the globe are due to various factors, of which winds, water currents, the relative size of land and water mass, and mountain ranges are probably the most important.

Types of Tropical and Subtropical Habitats. As a result of prevailing winds, ocean currents, relation of land and sea masses, elevation of land, and numerous other contributing factors, the climates of the globe may be classed as "dry," "dry-wet," and "wet." "Dry" designates an essentially desert area, with minimal rainfall. "Dry-wet" indicates seasonal alternation between periods of relative dryness and precipitation, as in India, for example, where rainfall is limited to the estivo-autumnal monsoons. "Wet" constitutes an area in which rainfall occurs rather abundantly throughout the year. Moisture, temperature, and elevation determine the type of *flora*, and indirectly, the *fauna*. In the tropical belt, there may be a luxuriant tropical rain-forest (essentially impenetrable jungle), either coastal, as in the Guianas, or far inland, as in the Amazon and Congo basins. In the higher valleys of warm climates, there may be temperate-zone deciduous and evergreen forests, and on the higher elevations, alpine forests and tundra. Moist lowlands may be essentially free of trees but covered with luxuriant swampy savannas. In the more temperate regions, there may be extensive grassy plains (for example, the midwestern plains of the United States and the pampas of Argentina). Areas of minimal rainfall may be covered with xerophytic scrub growth or may be entirely barren save for occasional oases. The climatic features of essentially all major localities of the world have been described in graphic form in an atlas by Walter and Lieth (1960).

Faunistic Areas of the World. There are six main faunistic areas of the Earth, determined primarily by the essentially different types of mammals in the respective areas. These areas are as follows (Fig. 2–1):

1. *Palearctic*, which includes Europe, Africa north of the Sahara, northern Arabia, and northern and central Asia
2. *Nearctic*, which includes North America as far south as central Mexico. In many respects, this region is the counterpart in the Western Hemisphere of the Palearctic in the Eastern Hemisphere
3. *Neotropical*, which includes southern Mexico, Central America, the West Indies, and South America
4. *Ethiopian*, which includes all of Africa but the Mediterranean coast; also, the adjacent islands and the southwestern tip of Arabia
5. *Oriental*, which includes all of India except the northern mountainous regions; Burma; Thailand; Malaysia; the Indonesian Islands exclusive of New Guinea; the Philippines; Vietnam; Taiwan; and southern mainland China
6. *Australian*, which includes Australia, New Guinea, and other Melanesian islands as well as New Zealand.

In addition to the above areas, there is the Micronesian region of the Central and South Pacific (Oceania), which has a relatively distinct fauna.

CLIMATE AND ITS EFFECTS ON MAN

Various physical factors influence the climate in different parts of the globe, and climate, in turn, is responsible for different flora and fauna. Thus, consistently dry conditions produce a desert, and consistently heavy precipitation in warm climates or during warm seasons in cooler climates is responsible for luxuriant growth of vegetation. Moreover, in much of the temperate and some of the subtropical areas, as in the United States, Europe, and the U.S.S.R., there are frequent periodic cyclonic disturbances that have a general direction from west to east and produce an alternation of high and low atmospheric pressures. At times these are modified by storm paths from the outside; in

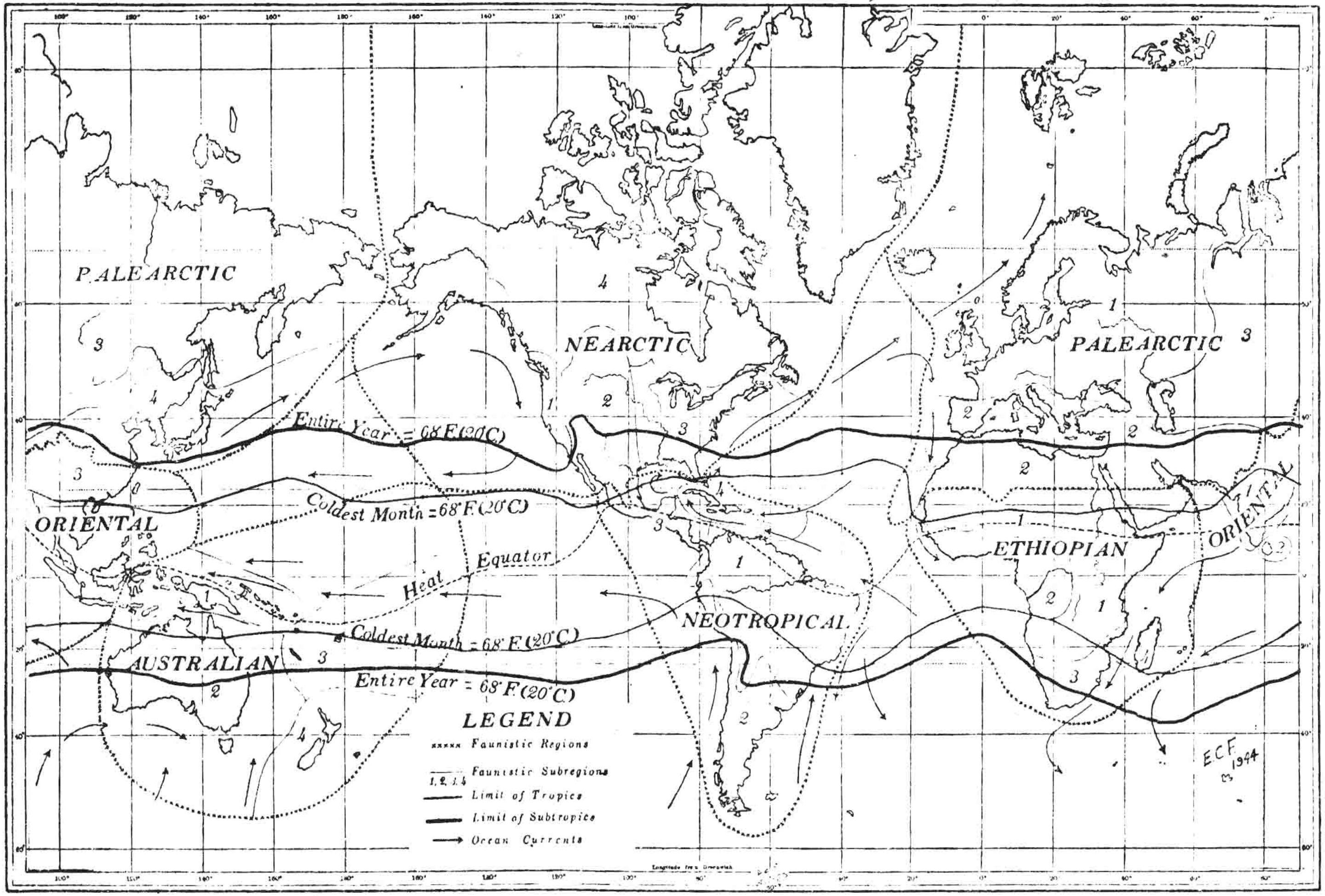

Fig. 2–1. World map, Mercator projection, showing the equatorial isothermic boundaries of the Tropics and Subtropics (Supan's lines in red: thin line shows limits of the Tropics, thick line limits of the Subtropics), principal ocean currents, and the six faunistic regions (see text) and subregions (1–4) of the earth. (By E.C. Faust.)