

MANAGEMENT

A wide range of preventive strategies have been applied to the control of parasitic diseases. Parasites move between hosts by horizontal (e.g. venereal, faecal-oral, water-borne, food-borne, predator-prey, air-borne, vector-borne) and vertical (transplacental, transmammary) routes of transmission. Infections can therefore be prevented by interrupting transmission cycles by manipulating host and environmental factors using management strategies to change:

- biotic factors (distribution and abundance of hosts, vectors, animal reservoirs);
- abiotic factors (physical and chemical environments affecting organismal survival); and
- sociological factors (cultural norms in hygiene, nutrition, housing, healthcare).

BIOTIC FACTORS

Effective control programmes rely on an intimate knowledge of the organisms involved, the environments in which they live, and their interactions. Differentiating parasites as the aetiological agents of infectious diseases from other causes (viruses, bacteria, fungi) requires considerable expertise by medical and veterinary personnel, with working experience of a range of biological entities: including parasites, hosts, and vectors.

Parasites

Many unicellular and multicellular organisms are parasitic in other animals, so clinicians and associated healthcare workers require comprehensive knowledge of many different life-forms. Recognizing patterns of infection and disease attributable to particular groups of parasites is difficult, because there are inevitably many exceptions to the rule. Generally, parasitic protozoa are associated more often with acute transient diseases as they may multiply rapidly within host tissues, while parasitic helminths and arthropods often cause persistent chronic diseases as they slowly accumulate in or on hosts. Effective management depends on reliable diagnosis, which should take into account:

- what parasite species is/are present? (biodiversity and taxonomy),
- how many and where? (distribution and abundance),
- how are they spread? (transmission), and
- how harmful are they? (pathogenicity).

Diagnosticians need to consider the often perplexing concept of parasite biodiversity, conventionally defined as species richness (how many species are there?). This requires theoretical knowledge of what constitutes a species, and practical knowledge of how to differentiate them. In biology, a species is commonly defined as an interbreeding population of individual organisms that produces fertile offspring. This biological species concept emphasizes reproductive isolation, with the existence of biological factors (pre- and post-zygotic barriers) that impede two members from producing viable fertile hybrids. Regrettably, the genetic integrity of most parasite species is not known. Many parasite life-cycles are unknown, many protists only reproduce asexually, many platyhelminths are hermaphroditic, a few helminths and arthropods are parthenogenetic, and while most parasites cannot be cultured for experimental cross-breeding studies, some hybridization between 'species', strains and/or genotypes has been observed. Hopefully, molecular characterization studies will help us better define parasite species, particularly those implicated in disease outbreaks.

Parasite identity underpins their taxonomic classification, which should be phylogenetically informative and reflect kinship (evolutionary relationships). However, many of the taxonomic characters used to identify parasites (morphology, biology, biochemistry, genetics) are beyond the purview of individual workers, let alone primary producers. The differential diagnosis of diseases caused by parasites requires good cooperation between a variety of personnel (patients/owners, clinicians/nurses, laboratory/scientific staff, care-givers/farm-workers, etc.), whether it be prompted by necessity (disease occurrence requiring medical/veterinary consultation), health concerns (suboptimal growth and development requiring intervention), or risk assessment (surveillance/screening associated with preventive maintenance, research, and/or quarantine). Researchers should endeavour to develop, refine, compare and evaluate different diagnostic tests, both direct detection methods and indirect presumptive methods. Government and commercial concerns should incorporate both conventional and emergent technologies into diagnostic laboratories, ensuring tests are reliable, rapid and cheap. The consequences of testing should also be transparent, with test results influencing decisions to isolate, treat or cull infected individuals. Many parasitic diseases have been made notifiable diseases in various countries with regulations governing translocations, testing, quarantine, treatment or disposal.

The distribution and abundance of parasites is often intimately linked to parasite fecundity, which is a numbers game balancing the number of offspring with their survival. In zoology, the fitness of a species can be fundamentally enhanced by two different strategies: fast reproduction (multiplication, replication) or prolonged development (long-life, stability). This is called *r/K* selection (derived from the logistic growth model of population biology), with *r*-selected species investing in reproduction (quantity) while *K*-selected species invest in prolonged development and long-life (quality). Many parasite species have rapid life-cycles (days-weeks) and produce huge numbers of encysted offspring (ova or cysts) which are broadcast into the external

environment in the hope that some will encounter new hosts. Other parasites infecting gregarious hosts that live in close contact with each other produce fewer offspring or non-encysted stages that are more likely to encounter new hosts. Some parasites have slow maturation times, either as larvae or as developing adults, and remain in individual hosts for long periods. Other parasites are transient and only infect hosts for part of their life-cycles, with other stages living free in soil or water. Knowledge of the kinetics and dynamics of parasite reproduction helps to understand their temporal and spatial distribution, but information is also required as to their survival capabilities inside and outside of hosts.

Epidemiological studies have helped identify seasonal and/or geographic patterns to infections in domestic and wild animals, and there is much speculation about what factors affect parasite survival, longevity, dispersal, viability and infectivity. Experimental studies have tested various physico-chemical factors (esp. temperature, humidity/moisture) on the survival and infectivity of exogenous parasite stages (eggs, cysts, larvae, nymphs, or adults) to gauge the duration and degree of environmental contamination. Pathological and immunological studies on experimentally infected animals have also helped understand the course, duration and severity of infections as moderated by host defences. Field studies have shown many parasites to have aggregated (over-dispersed) distributions whereby most parasites are found only in a few hosts. This begs the question, was this coincident to exposure or due to differences in host susceptibility?

Despite centuries of observations, little is actually known about the host ranges (zoogeography) and host specificities of most parasites. Studies often indicate host preferences rather than true specificities governed by molecular, physiological, biochemical and/or behavioural compatibilities. Host species differ greatly in their innate susceptibility/resistance to particular parasites, often with variation observed between breeds, age cohorts and sometimes sexes. Transmission success between hosts often reflects the chances of parasites encountering hosts in aquatic and/or terrestrial habitats, depending on their relative densities, distributions and susceptibilities. Parasites may have direct life-cycles involving one host species or indirect life-cycles involving multiple host species. Several mathematical models have been developed for population biology, with SIR models developed for microparasites (e.g. protozoa causing acute transient multiplicative infections) and HPW models for macroparasites (e.g., helminths and arthropods resulting in chronic prolonged cumulative infections). These models may help predict transmission patterns, but they cannot presage disease severity as they do not cover variations in parasite pathogenicity.

In microbiology, it has long been known that certain criteria need to be met in order to show cause-and-effect, that is, to determine whether a particular microbe is the cause of a particular disease. These criteria are known as Koch's postulates and they state that the specific microbe must: be present in all cases of the disease; be isolated from diseased patients; cause disease when re-introduced to a healthy susceptible animal model; and then be isolated again from the new host. It is difficult to satisfy all of Koch's postulates for most parasites, as many species cannot be cultured *in vitro* or *in vivo*. In addition, multiple parasite species may occur within individual hosts, but only a few species (or strains!) may be pathogenic and cause enough cumulative damage to cause clinical disease. Parasites vary greatly in their pathogenicity (virulence) due to different invasion, feeding, migration and/or sequestration activities, and hosts vary greatly in their susceptibility to disease due to innate genetic resistance and/or acquired immunity. This has led to what has been termed an evolutionary arms race between parasite virulence and host immunity. Hosts are under pressure to evolve resistance to parasites, while parasites are under pressure to evade host immunity and achieve successful infection. It is not in the best interest of a parasite to kill its host and thus deprive itself of a home, and it is also not in the best interest of the host to expend so much energy killing parasites with potential immunopathological consequences. It appears that the best outcome involves a stable balance between the two competing strategies which leads not to the extinction of one or the other, but to their mutual co-existence (often referred to as enzootic stability).

Knowledge of all these host-parasite interactions is vital for disease control, as it helps guide which interventions may best impact on disease occurrence and spread, without upsetting any equilibria. Detailed information on parasite abundance, distribution, longevity, infectivity and pathogenicity allows decisions to be made with respect to the urgency and timing of treatments and assessing the scope of the problem for local and regional communities. Great reliance is placed on the knowledge base and experience of individual clinicians to make informed decisions for the treatment and control of infections, particularly involving episodic outbreaks. Recently, several computerized mathematical models have been developed to help schedule treatment times and other interventions (mostly for ectoparasites and gastrointestinal nematodes in ruminants), based on multiple parasite bionomic factors influenced by prevailing weather (temperature, moisture, rainfall), microclimate (photoperiod, circadian rhythms), macroclimate (seasons), vegetation (type, structure, density), geographic location (latitude, longitude, elevation), land-use (cropping, pastoral, bush) and animal husbandry (breeding/feeding history, facilities, health management). Hopefully, these aids will become more readily available in the future to assist producers and communities in designing effective intervention programs to control parasitic diseases.

Hosts

Control programmes may not be able to actively manipulate parasite stages, but they can manage host populations, mostly in farm situations (agriculture and aquaculture), zoos and fauna parks, and occasionally in free-ranging wild animals. Parasitic infections are significantly under-diagnosed because clinicians usually only see patients sick enough to have sought medical/veterinary intervention. Asymptomatic, subclinical and mild symptomatic infections may be overlooked completely because the hosts are not sick, or not sick enough to seek help. Clinical disease therefore represents the ‘tip of the iceberg’, with infections below the ‘water-line’ contributing to the long-term persistence and on-going spread of parasites. Clinicians working with sick individual patients should always consider the broader community, particularly those placed most at risk (usually by virtue of cohabitation or other forms of close contact). It is also important to determine the role the different hosts play in parasite transmission: whether they are definitive hosts producing infectious stages, intermediate hosts in which parasites develop asexually, or paratenic hosts that transport parasites without further development. The adoption of control strategies by human communities or populations depends largely on the sophistication of the health infrastructure systems in place, while the management of animal populations varies considerably depending on the type of animals involved (production, performance, companion, show, feral or wild animals).

Humans

The growth rates of human populations are closely linked to the level of economic development, with growth rates in the poorest countries being twice that of developed countries. Populations are becoming increasingly urbanized (concentrated in cities) due to the migration of people from rural areas. As of 2010, more than 50% of the global population live in urban settings, but in some areas of Asia and Africa, the majority (>60%) still live in rural environments. Urbanization appears to be a feature of strong economies (higher per capita income), facilitating access to better healthcare, education, sanitation and cleaner water. However, cities are also home to great inequities between the rich and poor, with overpopulation and socioeconomic disparities leading to urban slums with unsafe dwellings lacking utilities. Urbanization may be viewed as a ‘mixing-cup’ or patchwork of social behaviours, subcultures and communities, sometimes acting as ‘pace-makers’ for local epidemiology (providing bridges between people and ecosystems and hubs for the spread of diseases). Epidemiological studies have linked infections with particular demographic groups, according to age, gender, affluence or socioeconomic status, profession and leisure pursuits. Two factors in particular predispose for more frequent and more severe infections in human populations, those occurring in regions with warm moist climates and those in poor communities. Indeed, climate and poverty are the most significant ‘drivers of disease’ in human populations, followed by poor nutrition, untreated drinking water, limited sanitation, and restricted healthcare. Historically, cities were regarded as ‘cess-pools of infection’ leading to the emergence of many so-called ‘crowd’ diseases (New World communicable diseases) associated with our concentration into small contaminated environments. In contrast, rural communities continue to harbour Old World zoonotic diseases with significant animal-to-human transmission due to the greater and closer proximity to animal and vector populations. With increasing globalization and further rural and urban development, we are now encountering a new wave of ‘emergent’ diseases, often linked to travel, animal translocations, bushmeat or wet markets, farming exotic animals, or encroaching on new geographic regions inhabited by wildlife (particularly rats, bats, birds and insects).

In addition to conventional chemotherapeutic treatments and the promise of protective vaccines (topics covered earlier), a range of other options are available to help control parasitic infections and disease. Clinicians may sometimes resort to surgical interventions for certain conditions, where parasites occur in accessible anatomical locations and are large enough to be extracted (e.g. auguring ectoparasites from the skin) or where lesions can be excised (e.g. onchocercal nodulectomy) or drained (e.g. amoebic abscesses). A range of modern techniques have also been explored for other surgical interventions, such as cryotherapy, electro-desiccation and laser photocoagulation. Supportive therapy may also be provided to relieve dehydration, fever, diarrhoea, inflammation, pruritis, hypersensitivity and secondary bacterial infections. Alternative therapies are also available for a range of conditions, such as cooling preparations for dermatitis and various ointments and poultices for open lesions. Many alternative treatments for ectoparasitic infestations may be used to disrupt their respiratory function or structural integrity, including occlusive dressings (natural and synthetic oils and pastes), aromatic compounds, alcohols, stringent antiseptics, alkaloids, eyedrops, desiccant dusts and even raw meat poultices (the latter to entice maggots out of wounds). Much can be done to prevent parasitic diseases in humans by improving sanitation (waste management) and hygiene (personal, food and water), which often involves changing people’s perspectives and behaviours.

Animals

Parasitic infections have been reported from a huge range of vertebrate animals, including farmed, companion, zoo, feral and wild species of mammals, birds, reptiles and fish. Disease control interventions that may be applied to these animals typically depend on the quantity and quality of husbandry and care provided. Obviously, more interventions can be imposed on intensively-farmed animals and pets rather than extensively-farmed animals, while interventions impacting on free-ranging wild or feral animals are more limited. In all cases, it has long been known that individual animals vary in their susceptibility to infection and disease, often related to their immunocompetence. Animals most at risk include young and old individuals, females when pregnant or lactating, immunodeficient individuals (congenital or acquired), immunosuppressed individuals (due to chemotherapy or concomitant infections) or those subject to high levels of stress (physiological, nutritional, or behavioural stress due to capture, handling, transport, crowding, breeding, weaning, poor diet, abrupt changes in environment, poor water quality, or treatment for other disorders). Every effort should be made to keep hosts well-fed, healthy and happy in stress-free conditions to bolster their defences against parasites.

Many species of animals are farmed for meat, milk, fibre, eggs and/or power, with increasing demand driven by population growth, higher incomes and urbanization. While agriculture and aquaculture are becoming more sophisticated in developed countries due to increased mechanization and technological advances, many communities in poorer developing countries still rely on subsistence farming often using traditional methods. Intensive farming practices may be economically sensible but they can lead to situations predisposing to disease outbreaks, as hosts become crowded into smaller areas which may become heavily contaminated by parasites. A variety of common-sense procedures can be used to reduce the risks of parasite transmission through good husbandry; including the provision of clean food and water sources, strategic grazing management (staggered, rotational, alternate, mixed grazing), pasture improvement (vegetation, drainage, discing), sensible stocking (cohort separation, avoid overcrowding), waste removal (organic matter, including dung, litter, bedding, carcasses), improved hygiene (clean holding facilities, fomite decontamination, handwashing, footbaths, filth and wound management), regular health screening (leading to isolation, quarantine or culling infected individuals), coordinated breeding (stock and season selection), and maintaining accurate stock records (provider, purchaser, performance, contact tracing). Producers are becoming more aware that stock can be selectively bred for disease resistance without sacrificing productivity, but breeding programs should be based on more than intuitive or casual observations and include hard data on parasite burdens and host developmental traits. In the past, various surgical procedures have been used to prevent ectoparasitic infections in animals (e.g. tail docking, castration and Mules operation to combat fly strike in sheep), but some procedures have fallen into disfavour due to market pressures or ethical concerns.

The control of infectious diseases in companion and performance animals is a lucrative industry, with considerable money spent on pets and leisure, sports and show animals (including those in aviaria, terraria and aquaria). Many conventional and alternative products are available for therapeutic treatments as well as for preventive prophylaxis, with keen advertising supporting sales of parasiticides, repellents and remedies against endo- and ecto-parasitic 'scourges'. A huge range of processed foods is available together with dietary supplements, water additives, clothing and other tack. Many devices are available to groom animal coats and/or remove ectoparasites (clippers, brushes, combs, tweezers, forceps, shampoos, conditioners). Special housing is promoted for different animal species, ranging from horse stables to dog kennels to bird cages to goldfish bowls. Behaviouralists advocate animal training to socialize pets, curb aggression and hunting, and enhance performance. Local and national governments have developed many regulations addressing such diverse issues as animal welfare, cruelty, abandonment, transportation, import/export, breeding, boarding, agistment, rescue and waste management. Despite such fanfare, parasitic diseases are still problematic in many regions due to poor compliance with chemical control protocols, the emergence of drug-resistance in parasite populations, the persistence of ectoparasites in peri-urban environments, and the indiscriminate faecal contamination of communal areas.

The management of wild animal populations is difficult but is becoming increasingly desirable mainly for conservation reasons. The impact of parasites on wildlife is hard to ascertain as sick animals may succumb to disease or predation without being observed, while animals with lighter or cryptic infections continue to be ambulatory and spread infections. Many parasite species have sylvatic cycles of infection, but a growing number of wild animal species have been found to act as reservoirs of infection for humans and domestic animals, with periodic or sporadic cross-over to rural and even urban hosts. Considerable resources have been deployed to control feral or pest animal species that are damaging ecosystems, usually by killing them (by hunting, trapping or poisoning), but sometimes by manipulating their reproduction (by sterilization or introducing sterile competitors). In areas where large herds of ungulates undertake seasonal migrations near farmlands, some measure of control has been imposed by diverting natural migration routes or providing corridors for their passage. It is prudent to use strong barriers (fences, screens) to exclude vermin and vectors from farms, fodder stores and domiciles, and to restrict the scavenging and hunting behaviours of resident carnivores. The annual migration of wild birds between feeding and breeding grounds presents an interesting paradox. It was thought that long distance migrations would be conducive to the spread of parasitic infections, particularly when animals are stressed by poor nutrition, crowding and over-exertion. However, unhealthy birds may not be able to fly long distances which prevents infections from escaping endemic regions. The culture of fish and shellfish in natural water bodies (estuaries, fjords, sea-cages, streams, dams) can be problematic when wild species (including pests and predators) infiltrate containment areas. Aquaculture enterprises should attempt to minimize incursions by intruders using barriers or other deterrents, but without compromising water quality.

Vectors

Many parasite species are transmitted between vertebrate hosts by a range of invertebrate vectors, including insects (flies/mosquitoes, fleas, lice), acari (ticks, mites), molluscs (snails) and crustaceans (copepods). These vectors act as definitive hosts if they support sexual development by the parasites, as intermediate hosts if they only support asexual development, or as paratenic hosts in which no parasite development occurs. Many arthropod vectors feed on vertebrate blood and may transmit parasites by injecting them as they bite, by contaminating wounds as they feed, or by being eaten by vertebrates. Trematodes utilize molluscs as amplification vessels which support the massive asexual reproduction of cercariae which escape into aquatic habitats to infect vertebrates. The larvae of some filarial nematodes develop in aquatic copepods and are ingested by vertebrates drinking water. While many studies have been conducted on vector biology to determine their distribution and developmental cycles, relatively few studies have compared the competence of different vectors for individual parasite species. Much of our knowledge comes from epidemiological studies in isolated regions. Clearly, further studies are required on the roles that vectors play in the transmission of parasites. Molecular biological techniques are now being used to screen vectors for specific pathogens, spawning an era of molecular epidemiology. However, the results need to be supported by experimental studies on parasites in vectors to quantify their proliferation (multiplicative potential), viability (survival, longevity, infectivity) and routes of infection (ingestion or excretion, inoculative or contaminative) to determine their relative importance in transmission cycles.

While vector populations may be huge in number and widespread in natural environments, various interventions have been applied to reduce host contact with vectors, including physical barriers, toxic chemicals or biological control strategies. Human habitations and animal holding facilities may use window and door screens to exclude arthropods and the buildings themselves should be properly maintained to eliminate entry points (holes) and hiding spaces (cracks). Bed nets have been used with great effect to protect sleeping areas from mosquito vectors in many countries with endemic malaria and viral fevers. Personnel may use protective clothing when moving around outdoors, especially with fabrics impregnated with arthropodocidal or repellent chemicals. A wide range of anti-parasitic chemicals have been developed for the therapeutic treatment of infected hosts and for prophylactic treatments to prevent infections in host at risk. Some chemicals have also been shown to work effectively against vector populations not directly associated with hosts, that is, when applied to vector habitats (such as resting or breeding sites). Insecticidal, acaricidal and molluscicidal chemicals may be used in terrestrial and/or aquatic environments in traps, baits, sprays, fogs, mists, surfactants or water additives, deliberately targeting free-living vector stages. However, considerable caution is advised when using toxic chemicals in the environment to make ensure collateral damage does not damage ecosystem health and to avoid conditions conducive to the development of drug resistance in vectors (an infamous example involves the widespread use of the insecticide DDT which has now been banned since 2004). Investigations into natural plant products with pesticidal properties led to the development of pyrethrin insecticides, and studies are examining a variety of other plants thought to have toxic or repellent activity against different vectors.

Biological control programmes show considerable promise for more environmentally-friendly and holistic approaches to reduce vector populations. Vectors usually have free-living stages that are subject to attack by predators (such as wasps, hornets, flies, ants, beetles, spiders, mosquito fish and grooming birds) as well as a range of pathogens, including entomopathogenic fungi, nematodes, microsporans, viruses and bacteria. Some bacteria have been found with natural insecticidal endotoxins (e.g. *Bacillus thuringiensis*), and others have been found to manipulate vector reproduction (e.g. *Wolbachia* spp. exhibiting selective male killing, sterilization or feminization in some insects). Over the years, many programmes have been developed to decrease vector reproduction rates by breeding and releasing sterilized or transgenically-modified males to compete for mates (strategies well investigated for the control of peri-urban mosquitoes carrying human viral diseases). Some of the greatest impacts made on vector control have involved habitat alteration or destruction, notably the draining of swamps near cities suffering from malaria (an intervention used centuries ago in Europe to reduce bad odours ('mal-airia'), but now known to have eliminated the breeding grounds of the mosquito vectors). Many management strategies continue to be developed in rural and urban communities to reduce vector breeding sites, ranging from eliminating temporary puddles to rehabilitating waterways to strategic land clearance.

ABIOTIC FACTORS

Most parasites do not live permanently in or on their hosts or vectors, but have free-living stages in the external environment (terrestrial and/or aquatic) as non-motile encysted stages (ova, oocysts) or motile host-seeking stages (immature larvae, nymphs, swarmer or mature adults). They are therefore subject to the prevailing environmental conditions (physical and chemical factors) which can impact on their survival and dispersal. While humans may not be able to manipulate global (or large-scale) environmental conditions, recognition of the factors detrimental to parasite survival, but still favouring host survival, can facilitate subtle manipulation of local (small-scale) conditions. Considerable success has been achieved in the control of many parasitic diseases by changing abiotic (non-living) components through:

- environmental management,
- climate prediction,
- improved sanitation,
- ensuring food security, and
- countering air pollution.

Environment

Parasites and their hosts (including vectors) share the same physical environment, with many modes of transmission involving environmental contamination by infective stages (e.g. water-borne, food-borne, faecal-oral, vector-borne). To better understand parasite transmission, basic knowledge of environmental composition is required together with specific knowledge of the survival characteristics of parasites within those environments; particularly: terrestrial environments (soil and vegetation); aquatic environments (freshwater to marine); as well as on inanimate objects (fomites).

Terrestrial

Terrestrial environments involve many different types of landscapes, varying in topography, geology, hydrology, vegetation and utilization. The Earth's surface comprises 29% land and 71% ocean. Of the 141 million km² of land, 76% is considered habitable, with the remainder being barren (e.g. deserts) or covered by glaciers. Almost half (45%) of the habitable land is used for agriculture, with the remainder comprising forests (38%), shrublands (13%), wetlands (3%) and urban development (1%). Two-thirds of agricultural land is used for grazing livestock (meat, dairy) and one-third for cropping (food, biofuels and textiles). Parasites in these different terrestrial environments are influenced not only by their physical and chemical characteristics but also by land utilization. The most visible mark that humanity has left on the planet is the transformation of wild habitats into farmlands. Parasites often benefit from farming practices as hosts are crowded together in small contained areas subject to greater contamination. Different soil and vegetation types have been shown to affect parasite survival, or that of their vectors. For example, gastrointestinal nematode larvae are more active on moist pastures, snail vectors for trematodes are more abundant in wet soils, while *Tunga* fleas prefer warm dry sandy soils. Knowledge of parasite behaviour and survival under different conditions is vital for the alteration and implementation of farming practices that help reduce parasite contamination and transmission. For example, some parasite burdens can be reduced by draining or discing wet soils, by using rotational grazing, and by spelling pastures over hot dry summers. There are numerous anecdotal and proven farm management interventions that can help control parasitic infections and disease, depending on our knowledge of the parasite involved.

Aquatic

Water is a vital and precious resource for life on this planet. Over 97% of water occurs in oceans as saltwater, another 2% is locked in glaciers, while only 1% is available as freshwater. Water is a perfect medium for the transmission of motile parasites as well as the carriage of non-motile developmental stages. For example, many parasites have flagellated or ciliated stages that actively swim in water seeking hosts, while others have encysted buoyant stages that serendipitously make contact with hosts or are ingested with drinking water. Other parasites utilize aquatic invertebrates as amplification hosts or as vectors for transmission, and some parasites ascend the food chain when big hosts eat small hosts. The survival of all these aquatic parasite stages depends largely on their tolerances to the chemical and physical properties of their watery habitats, particularly temperature, salinity and oxygenation. Parasites vary in their thermal ranges, some preferring colder waters than others, but they do not survive long in hot or freezing conditions. Their salt tolerances are often narrow enough that temporary freshwater baths may be used to treat some ectoparasites on marine fish, and conversely, saltwater baths may be used to treat ectoparasites on freshwater fish. Few parasite species survive in nutrient-rich eutrophic waters which often support bacterial and algal blooms robbing the water of dissolved oxygen. Invertebrate vectors also have specific requirements for their reproduction and survival; for instance, blackfly vectors breed only in flowing waters, while mosquito vectors breed mainly in stagnant waters. Knowledge of parasite biology in aquatic environments allows for various interventions to be included in environmental management programmes to modify aquatic habitats and biota to help reduce parasite transmission.

Fomites

Inanimate (non-living) objects may also carry infectious agents. These 'fomites' include a wide range of natural and artificial objects used for human habitation (buildings, fittings, furniture, clothing, utensils), farming (equipment, barns, yards, cages, nests, bedding), and transport (vehicles). People need to understand the mechanisms by which fomites become contaminated and how to decontaminate them. Contamination usually occurs via host secretions/excretions containing parasites, including faeces, urine, vomitus, sputum, phlegm and scurf. Vectors may also utilize fomites for shelter or breeding, particularly when they contain plentiful hiding places in the form of cracks, crevices or holes. Human and animal housing should be regularly maintained or repaired to eliminate sanctuaries, taking care to avoid conventional porous building materials (weathered wood, mud adobe, straw roofs, earthen floors) and using nonporous materials (hardwood sealed timber, fired bricks, ceramic tiles, plastered walls, steel tubing, roof tiles, tin roofs, concrete floors). Newer fomites are also easier to decontaminate using heat (hot washes, steam-cleaning), suction (vacuum cleaning), radiation (ultraviolet light), stringent chemicals (surfactants, solvents, bleaches), and toxic chemicals (insecticides, acaricides). Insect repellents may also be applied to absorbent materials (such as clothing, bedding, rugs, grooming equipment, harnesses, saddlery and other tack). Utilization of shared spaces should be monitored for cross-contamination, with physical and/or chemical barriers used for separation, isolation or quarantine. If required, personnel may adopt personal protection procedures, similar to those used for barrier nursing.

Climate

Many parasites exhibit temporal and spatial variations in distribution and abundance related to weather conditions. The climate of any region is generally defined as its average weather prevailing over time (at least several decades). While many physical elements contribute to the weather, the most important for parasites are temperature and moisture (as influenced by many other factors, such as sunshine, cloudiness, precipitation, humidity, air pressure, wind, evaporation). Free-living or exogenous parasite stages usually require warmth and moisture to survive, as do their hosts and vectors. Many climatic zones are recognized around the world, most exhibiting annual seasonal fluctuations in weather. Some regions also exhibit longer non-annual cycles, for example, El Nino-Southern Oscillation (ENSO) patterns across the Pacific every 5-7 years. The world is also experiencing global climate change for a variety of reasons, including greenhouse gas emissions from industry and agriculture. The impact of climate change is difficult to predict, and various models have attempted to forecast the scope of changes. In addition to overall warmer temperatures, many agree that the frequency and magnitude of extreme weather events will increase with far-reaching impacts on the environment; involving storms, floods, droughts, soil erosion, desertification, ice loss, and rising sea levels. The geographic distribution of hosts, vectors and parasites will change as regions vary in temperature and moisture levels with different seasonal patterns emerging. Human and animal populations must adapt to changing circumstances and implement different management options as appropriate, rather than rely exclusively on historical records and trends.

Sanitation

Humans and animals regularly produce large quantities of organic wastes which may transmit infectious microbial diseases. Waste products come in many forms, such as excreta (faeces and urine as sewage or manure) as well as other household, industrial and agricultural wastes (wastewater, greywater, effluents, food scraps, garbage). The effective collection, storage, treatment and disposal of waste is therefore paramount to disease control. Humans have changed their toilet habits over centuries from indiscriminate defaecation to using latrines, open cesspits, and toilets leading to closed septic tanks or sewerage collection systems. However, it has recently been estimated that 1 in 5 people still defaecate in the open, and nightsoil is still used in some areas to fertilize vegetable gardens. Sewage treatment plants have been developed to treat waste materials by filtration, sludge activation, and biocomposting, but they can become overloaded or compromised by flood events. Excrement from animals is voided into the immediate environment leading to local contamination, and while some intensive animal industries may wash out animal pens or stalls, the waste is often not collected, stored or treated but simply washed elsewhere. Animal waste, including litter from poultry sheds and straw bedding from stalls, is also often used to fertilize gardens and crops. Aquaculture ponds generally feed into local streams or estuaries without undergoing any treatment, sometimes leading to organic enrichment and microbial blooms.

One of the greatest advances made in the control of infectious diseases was the introduction of effective treatment processes to provide clean potable (drinking) water, particularly the chlorination of reticulated water systems. Water may be decontaminated by removing microbes (by sedimentation, flocculation, filtration, or adsorption) or disinfected by killing microbes (by heat, chemicals (chlorination, ozonation) or irradiation (ultraviolet light or high energy sources). Numerous engineering solutions have been applied to the collection, storage, treatment and distribution of water to urban and rural communities, but many remote and under-developed regions still rely on natural catchments, open dams and untreated water supplies. Irrigation systems are becoming more prevalent in agriculture and land-based aquaculture is proliferating in many riverine and coastal regions. Disease control through waste management should still be practised where appropriate to avoid outbreaks, particularly in intensive culture systems. Many common-sense interventions can also be applied in local situations, such as water flow regulation to cleanse waterways, clearing vegetation from irrigation channels and ponds, avoiding stagnant waters, draining ditches and swamps, maintaining reticulation systems, treating biofilm accumulations, and controlling aquatic leisure activities such as swimming or boating.

Food

Much has been said lately about food security, not only about governments securing stable supplies (sufficiency) but also ensuring food hygiene (safe and nutritious). Malnutrition encompasses both over-nutrition (more calories/protein than required) contributing to obesity, and under-nutrition (insufficient calories/protein for maintenance) manifesting in physical and intellectual growth retardation, including low weight-for-age (underweight), low weight-for-height (wasting) or low weight-for-age (stunting). Poor nutrition also impairs host innate and acquired immunity, making malnourished individuals more susceptible to disease. Many regulations have been embedded in the different food industries to check food hygiene, with industry standards applied to inspection, disinfection, preservation, distribution, storage, expiration and disposal. It is sometimes difficult for individuals within this supply chain to accept responsibility for action or inaction, particularly when faced with strong economic imperatives. Many communities now advocate holistic coverage (e.g. gate-to-plate) involving producers, processors, wholesalers, retailers and governments, with defined lines of communication and accountability. This is critically important with the growing globalization of many food markets to avoid the accidental spread of infectious diseases.

Air

Environmentalists rightly decry air pollution by human industry, with many cited examples involving toxic chemicals. While many viral and bacterial diseases may undergo air-borne transmission involving aerosols, few protozoan or metazoan parasites are transmitted via aerosols. Some infections may cause respiratory signs involving mucus production, sneezing and coughing, but any expired parasites are too heavy and do not remain as air-borne particulates. They can settle and contaminate the surrounding environment (pastures and fomites), but such stages are often fragile and do not survive for long. Nonetheless, the recent Covid epidemic has amply demonstrated the efficacy and utility of personal precautionary measures in disease control, including wearing masks, handwashing, and modifying behaviours (e.g. social distancing).

SOCIOLOGICAL BEHAVIOURS

The greatest impediment to parasite control appears to be the difficulty in changing human behaviour. Many people persist in activities/behaviours which perpetuate parasite transmission and survival. They do so for a variety of reasons: such as historical precedence, adherence to social norms, habituation, resistance to change, lack of awareness, lack of alternatives, etc. These activities are often related to socio-economic status, which can be graded by such measures as life expectancy at birth, gross domestic product per capita, and educational attainment. Poverty is the single most important global determinant for infectious disease risk, with 'poverty traps' exposing vulnerabilities involving environmental, sanitary, nutritional, behavioural and healthcare components. Health security can also be adversely affected by natural disasters, famine, social upheaval and war, due to dysfunctional infrastructure systems, poor living conditions, and rampant anxiety. The global peace index includes components categorized as societal safety and security (internal peace such as violent crime, political stability, respect of human rights, displaced persons) as well as militarization (external peace, armed conflict, war). It is predicted that climate change, population growth, resource scarcity, ideological movements and shifts in global power may degrade global peace in coming decades. Throughout this changing milieu, individuals hold onto customs and traditions, sometimes fiercely so. However, history is not always a good teacher.

Customs and traditions

A custom is an accepted way of behaving/acting in a very specific area, society, place or time, whereas a tradition is a system of beliefs or behaviours passed down within a community or society with symbolic meaning or historical significance. Human populations frequently appreciate cultural diversity aspiring to cosmopolitanism and globalization. Some traditions, however, favour disease transmission. For example, the use of nightsoil (human faeces and urine collected overnight) to fertilize vegetable crops may enhance transmission of gastrointestinal parasites such as roundworms and amoebae. Experimental studies demonstrated that microbial biocomposting techniques could render nightsoil safe to use as a fertilizer in only a few days. Several poor communities were provided with biocomposting toilets, but subsequent studies found that parasitic infection rates did not decline. Investigation revealed that residents did not use the new toilets but continued to use nightsoil the old way because their traditions stated it must be used fresh as the vigour imparted to plants only lasted one day. Other examples involve barefoot natives being mandated to wear shoes to avoid acquiring geohelminth infections by transdermal larval penetration, and safe sex practices being advocated to pious communities to avoid sexually transmitted diseases. Many cultures have unique cuisines and cooking traditions that may facilitate food-borne transmission of parasites. The practice of eating raw or under-cooked meat can lead to the transmission of tapeworms (in pork, beef, fish and shellfish) and cyst-forming coccidia (e.g. toxoplasmosis). Many traditional methods of food preparation and preservation do not kill parasites contaminating foodstuffs, and while vegetables, salads and fruits may be cleaned by washing, the wash-water itself may be contaminated by parasites. It is therefore advisable that scientific methods be used to investigate food-borne outbreaks of disease and to identify the tolerances of different parasites to cooking and preserving processes, particularly with the globalization of many food markets.

Healthcare

Not everyone on the planet has access to modern healthcare in the form of reliable evidence-based information, diagnostic services, therapeutic treatments and ancillary care. Indeed, not everyone has the educational background to believe in the 'germ theory' that posits invisible entities cause diseases (now known to be pathogenic micro-organisms). Some degree of knowledge is required for compliance with routine personal hygiene (bathing, showering, hand washing, covering coughs and sneezes), home hygiene (cleaning fomites, vacuuming dirt, laundering clothes and bedding) and the discontinuation of other nonhygienic practices (such as spitting saliva, phlegm or sputum, and not eating soil (geophagia or pica)). Local, regional and national authorities should endeavour to provide contemporary public health amenities, including communal sanitation, water treatment, disease surveillance, epidemiological investigations, risk assessment and facilitating appropriate health treatments through clinics, animal health advisers, community nurses and clinicians. Action should be taken to remediate strange and inappropriate traditional treatments, such as discouraging the use of raw meat and frogs as poultices for open wounds. Every effort should be made to provide and promote cost-effective interventions for disease control, and to assess their acceptance and efficacy in the field. Public education campaigns should be developed to explain and implement control programs, particularly where people are required to change ingrained behaviour patterns. Education programmes are most effective when they target specific diseases rather than providing general advice. Media coverage should include conventional print (newspapers, posters, billboards, stickers, pamphlets) and modern audiovisual aids (radio, television, mobile phones, and internet sources with advertisements, commentaries and testimonials). The general public should be given specific advice with recommended courses of action and recommended timelines, preferably with incentive and reward schemes to support implementation rather than punitive schemes to punish miscreants.

INTEGRATED MANAGEMENT

Parasite control programs should adopt an integrated approach whereby multiple interventions can be practiced in attempts to reduce the incidence of parasitic diseases. The 3 main components involved are logically the parasites (P) themselves, the hosts (H) they infect, and the environments (E) in which they occur. Modelers have collated these components into a conceptual model (known as the HPE epidemiological triad) that attempts to address interactions between hosts, parasites, and their environments; quantified where possible in terms of dynamics (quantity) and kinetics (duration). For example, the thermal tolerances of protozoal cysts and worm eggs should be determined in terms of both temperature optima and exposure time. It has been said that the epidemiological triad imagines our struggle against infectious disease where significant progress can be achieved when you ‘know yourself, know your enemy, and know your battleground’. Having identified potential weak spots, interventions can be planned and implemented specifically targeting those interactions to reduce disease transmission and occurrence. Great successes have been recorded by implementing small ‘common-sense’ interventions; e.g. sleeping under bed-nets to avoid mosquitoes carrying malarial parasites, wearing shoes to avoid transdermal infections by hookworm larvae, straining drinking water to remove copepods bearing guinea-worm larvae, etc. Above all, people should be empowered through public education campaigns to make informed choices to change behaviours and engage in sensible, reliable and cost-effective disease control procedures. Knowledge is power!

