1 The development of veterinary medicine

Veterinary epidemiology is concerned with disease in animal **populations**. Its evolution has spanned several centuries and has been central to the successful control of many animal diseases. This introductory chapter traces the development of veterinary medicine in general (including relevant aspects of human medicine), showing that it has been inseparably linked to that of veterinary epidemiology.

Although man's association with animals began in prehistoric times, the development of scientific veterinary medicine is comparatively recent. A milestone in this growth was the establishment of the first permanent veterinary school at Lyons, France, in 1762. Early developments were governed largely by economic rather than humanitarian motives, associated with the importance of domestic stock as a source of food and as working animals; and there are still important economic reasons for concern about disease in animal populations. Later, with the advent of the industrial revolution and the invention of the internal combustion engine, the importance of draft animals declined in the more-economically-developed countries. Although dogs and cats have been companion animals for several thousand years, it is only relatively recently that they and other pets have increased in importance as components of human society.

Until the last half of the 20th century, the emphasis of veterinary medicine had been on the treatment of individual animals with clearly identifiable diseases or defects. Apart from routine immunization and prophylactic treatment of internal parasites, restricted attention had been given to herd health and comprehensive preventive medicine, which give proper consideration to both infectious and non-infectious diseases.

Currently, the nature of traditional clinical practice is changing in the more-economically-developed countries. The stock owner is better educated, and, among livestock, the value of individual animals relative to veterinary fees has decreased. Therefore, contemporary large-animal practitioners, if they are to meet modern requirements, must support herd health programmes designed to increase production by preventing disease, rather than just dispensing traditional treatment to clinically sick animals.

In the less-economically-developed countries, the infectious diseases still cause considerable loss of animal life and production. Traditional control techniques, based on identification of recognizable signs and pathological changes, cannot reduce the level of some diseases to an acceptable degree. Different techniques, based on the study of patterns of disease in groups of animals, are needed.

Similarly, contemporary companion-animal practitioners, like their medical counterparts, are becoming increasingly involved with chronic and refractory diseases which can be understood better by an investigation of the diseases' characteristics in populations.

This chapter outlines the changing techniques of veterinary medicine by tracing man's attempts at controlling disease in animals, and introduces some current animal disease problems that can be solved by an epidemiological approach.

Historical perspective

Domestication of animals and early methods of healing

The importance of animal healers has been acknowledged since animals were initially domesticated, when they were already likely to have been chronically affected by various infections (McNeill, 1977). The dog, naturally a hunter, was probably the first animal to be domesticated over 14 000 years ago when it became the companion of early hunters, with evidence of close proximity to humans as early as 31 000 years ago (Germonpré *et al*., 2009); and differentiation from its ancestor, the wolf, was likely to have occurred at least 10 000 years ago, as hunter-gatherer societies gradually evolved into sedentary agricultural

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populations (Vilà *et al.*, 1997). Sheep and goats were domesticated by 9000 BC in the fertile Nile valley and were the basis of early pastoral cultures. A few of these societies have lasted (e.g., Pfeffer and Behera, 1997), but many were superseded by cattle cultures; in some, the pig increased in importance (Murray, 1968). An Egyptian cattle culture evolved from 4000 BC, and farming spread from the Near East into Europe (*Figure 1.1*). There is archaeological evidence of cattle shrines in Anatolia dating back to 6000 BC (Mellaart, 1967). This record illustrates that animals had religious, as well as economic, significance in early civilizations. The aurochs was central to the religion of the Sumerians, who migrated throughout Asia, North Africa and Europe in the third millennium BC taking their animals and beliefs with them. India is the largest cattle culture that remains. Cattle cultures also persist in north-east Africa, the result of interaction between the Ancient Egyptians and early Nilotic tribes. Cattle still play important roles in these cultures: they are food, companionship, and status and religious symbols to the Suk (Beech, 1911) and Dinka (Lienhardt, 1961) of South Sudan.

The first extensive colonization of the Eurasian steppe and semi-arid areas occurred in the third millennium BC. The horse provided the key to successful exploitation of the area north of the Black Sea, the Caucasus, and the Taurus and Zagros mountains (Barraclough, 1984), and a Eurasian horse culture, associated with warrior tribes, emerged (Simpson, 1951). Some of these tribes overran the older cattle cultures. The horse is represented in Iranian, Greek and Celtic pantheons. It has become a symbol of veterinary medicine in the form of a centaur, one of which, Chiron, was considered to be the mythological founder of Greek medicine.

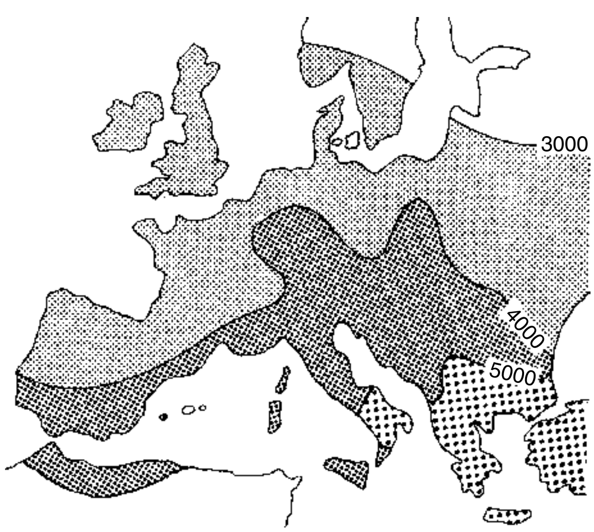

Figure 1.1 A generalized map to show the spread of farming from the Near East to Europe in years BC. (Adapted from Dyer, 1990.)

There have been several movements of animals with concomitant social and agricultural modifications since the early changes. The camel was introduced into Saharan Africa in the first century BC, and into the Sub-Saharan region around AD 400 (Spencer and Thomas, 1978; Phillipson and Reynolds, 1996), the latter already having well established domestic cattle and goat populations (Cain, 1999; Tefera, 2004). The Spanish introduced cattle, sheep, pigs and goats to North America in the 16th century. Haired sheep were introduced to Africa by European slave traders. The Spanish brought turkeys to Europe from North America.

The early Egyptian healers combined religious and medical roles by being priest-healers, often associated with temples. Their therapeutic techniques are recorded in the veterinary *Papyrus of Kahun* (*c.* 1900 BC). Literary records of similar age, describing veterinary activities, are extant from other parts of the world, such as Indian Sanskrit texts from the Vedic period (1800–1200 BC).

Changing concepts of the cause of disease

Concepts of the cause of disease have changed and evolved[1]. A method of treatment used by early Egyptians was incantation. This was partly ritual, but also reflected their belief in supernatural spirits as a possible cause of disease. Approaches to treatment and prevention are the direct result of theories of cause. There have been five main theories up to the middle of the last century[2]. One theory was often superseded by another, but traces of each still can be seen in different parts of the world.

Demons

Early man attributed disease to supernatural powers, the product of animism, which imbued all moving things with a spirit. In this 'spirit-world', disease could be produced by witches[3], superhuman entities and spirits of the dead (Valensin, 1972). Treatment therefore included: placation, for example by sacrifice; exorcism (forcible expulsion); evasion, for instance

[1] Causality is outlined in this chapter specifically in the context of disease. A more general discussion is presented in Chapter 3.

[2] Theories of the cause of disease also have similarities with theories of the origin of species, and both have rationalistic and theological dimensions (Bullock, 1992).

[3] A witch was originally defined as 'one who by commerce with the Devil has a full intention of attaining his (or her) own ends' (Bodin, 1580). Witchcraft became widespread in Europe between the 12th and 18th centuries. In the depositions of witch trials, there are many examples of the supposed induction of disease and death in man and domestic animals by witches (L'Estrange Ewen, 1933).

Figure 1.2 Plague allegory: the fate of gamblers and lechers. Giovanni de Paolo: *Allegory of the Plague*, Sienese, 1436–1437. (Reproduced with permission of bpk/ Kunstgewerbemuseum, Staatliche Museen zu Berlin/Saturia Linke.)

scattering millet seeds to avoid vampires (Summers, 1961); and transference, often to human and animal 'scapegoats'[4], probably the best known single example of which is the Gadarene swine (the Bible: *Mark* 5, i–xiii). The techniques included: ritual ceremonies; material objects that could be suspended (amulets and periapts), carried (talismans), hung in a building (fetishes and icons) or displayed in the community (totems); the use of special people such as witch doctors; and incantations[5]. The meaning of the Indian word 'brahmin' originally was 'healer' because the Brahmin were a class of healers. In the Neolithic period (4200–2100 BC), trepanation (the removal of a bone disc from the skull) may have been practised to release evil spirits from sick people (Buckland, 1882; Wakefield and Dellinger, 1939). The practice also is recorded in veterinary texts as early as the 16th century, but may be much older (Binois, 2015); and the Greek physician, Galen, practised trepanation on apes in the second century AD (Arnott *et al*., 2003).

During the 19th century, many European peasants still believed that diseases of cattle were caused by evil spirits, which could be kept at bay by fire (Frazer, 1890), and the African Nuer tribe occasionally still uses incantations during ritual sacrifice when cattle epidemics occur (Evans-Pritchard, 1956)[6]. Moreover, sacrifice was practised in England as late as the 19th century (Baker, 1974).

Divine wrath

The demonic theory involved many spirits; the next development, monotheistic in origin, argued that disease was the product of a displeased supreme being: disease was punishment for sinful behaviour (*Figure 1.2*). This belief is prominent in the Old Testament, for example, the animal plague of Egypt (the

[4] The scapegoat had the dual purpose of averting and magically transferring guilt and evil, both generally and at a specific time of crisis, such as plague or failure of crops. It takes its name from the Hebrew rites of the Day of Atonement when a goat was driven into the wilderness after the High Priest had ritually confessed the sins of the people and transferred them to the goat. The custom occurs universally from Ancient Babylonian times to modern times, where human sacrificial scapegoats have been known in some tribal societies (Cooper, 1990).

[5] Historical examples of the use of amulets, talismans and 'white witches' to prevent and control diseases of livestock in England and the British Colonies are given by Baker (1974) and, as late as the 19th century, 'white witches' ('charmers') were recommended by the Ministry of Agriculture's veterinarians (St Leger-Gordon, 1994).

[6] More recently, there has been a trend towards a contemporary understanding of disease (Hutchinson, 1996).

Bible: *Exodus* 9, iii) and is also evident in Persian and Aztec writings. The only effective treatment of disease induced in this way was placation because exorcism and evasion would not be effective against a supreme being. The English veterinary surgeon, William Youatt, writing in 1835, supported the practice of burning crosses on the heads of cattle to cure and prevent disease. In 1865, Queen Victoria, believing that the current British rinderpest (cattle plague) outbreak was the result of divine displeasure, ordered that a prayer should be used in each church in England while the epidemic continued. Beliefs in causation involving divine wrath are still evident today; for example, in some interpretations of the HIV/AIDs epidemic as punishment of the sinful (Kopelman, 2002).

Metaphysical medicine

The next development did not assume the existence of a supreme being, either demonic or divine, but assumed the presence of occult forces beyond the physical universe. This 'metaphysical' medicine embodied a theory of natural laws but excluded scientific principles such as observation and the repeatability of phenomena. The moon, stars and planets were considered to affect health (Whittaker, 1960), these concepts being obvious predecessors of astrology. Several outbreaks of rinderpest in Dark Age Europe were ascribed to earthquakes, floods and comets.

Treatment frequently included particularly foul medicines and practices that persisted for many centuries. A recommended 17th-century cure for broken wind in horses comprised toads, swallows and moles roasted alive and mixed with shoe soles[7]. Divination, practised by the Babylonians using sheep livers, and the 'Doctrine of Signatures' which suggested a similarity between the disease and its cure – for example, using toads to treat warts – were notable metaphysical developments.

The universe of natural law

A major intellectual revolution began in Greece in the sixth century BC in which the universe was rationalized without either demonic or metaphysical influences. The Greeks thought that disease was the result of derangement of four 'humours' of the body, which were associated with four properties (heat, moisture, dryness and cold) and with four elements (air, earth, water and fire) (*Figure 1.3*)[8]. Diseases were considered to be caused by external forces, including climatic and geological changes that affected the population. Local outbreaks of disease were thought to be the result of local eruptions of noxious air: **miasmata (miasmas)**[9]. The word 'malaria' literally means 'bad air' and hints at the 19th-century belief that the disease was caused by stale air around swamps. This belief led to European colonists preferring to settle away from such areas, often choosing higher altitudes. This strategy was beneficial because it moved the colonists away from the breeding sites of the actual vectors of the disease, *Anopheles* spp. mosquitoes.

The concept of humoral derangement was reimported into mediæval Europe, via Sicily, during the Crusades, and food was imbued with the same properties as the humours (Tannahill, 1968). The concept persists in several cultures. In indigenous Indian Ayurvedic human and veterinary medicine, based on the Hindu Scriptures (Vedas), there are three humours (tridosa): vata (wind), pitta (bile) and kapha (phlegm); derangement of vata, for example, causing asthma and diarrhoea. This concept is also central to modern Mahayana Buddhist medicine. However, in Europe, the popularity of the miasmatic theory declined at the beginning of the 20th century, by which time the microbial theory of infectious disease was adequately supported.

CHARACTERISTIC / CHARACTERISTIC	**Moisture**	**Dryness**
Heat	Humour = Blood Associated element = Air Source = Heart Excess → Sanguine temperament	Humour = Yellow bile Associated element = Fire Source = Liver Excess → Choleric (bilious) temperament
Cold	Humour = Phlegm Associated element = Water Source = Pituitary gland Excess → Phlegmatic temperament	Humour = Black bile Associated element = Earth Source = Spleen Excess → Melancholic temperament

Figure 1.3 Components of humoral pathology.

7 Such mixtures were essentially witches' concoctions, which could be formulated for either good or evil (Fletcher, 1896).

8 These elements were originally posited by the Presocratic Greek philosopher, Empedocles, who termed them 'roots' and associated them with the mythical individuals, *Hera*, *Aidoneus* (*Hades*), *Nestis* (*Persephone*) and *Zeus* (Kirk *et al.*, 1983).

9 This explains why urban Victorians draped thick curtains in their windows in an attempt to keep out disease. Miasmata were documented as being responsible for the initial development of the European plague epidemics (the Black Death) throughout the sixth and seventh centuries (Maddicott, 1997) and during 1347–1350 (De Smet, 1856).

The Greek idea of disease was susceptible to scientific investigation. Careful observation and the identification of specific causes became the hallmarks of the fifth-century BC school of medicine at Cos, and were refined by Hippocrates whose text, *Discourse on Airs, Waters and Places* (Jones, 1923), dominated medicine for many centuries. Therapy was consistent with causal concepts, and included purges and alterations in diet.

Contagion

The idea that some diseases can be transmitted from one animal to another has its ubiquitous origins in antiquity, and ancient veterinary accounts of disease provide strong evidence of the concept of contagiousness (Bodson, 1994). Galen and the Roman, Lucretius, believed that disease could be spread by airborne **seeds** or **animacula** (not necessarily living), which were taken in through the nose and mouth[10]. The Jewish Talmud describes demons as hiding 'everywhere' – in water, crumbs and air – implying transmissibility. The primitive Hindus associated sick rats with human plague, the first suggestion of a zoonosis. In the 14th century, the Tartars besieging the Genoese settlement at Caffa (Feodosia) in Crimea lobbed the corpses of plague victims over the city walls in the hope that this would spread the disease in the city (Ziegler, 1969). The Veronan, Fracastorius, writing in the early 16th century, argued that diseases were transmitted by minute, invisible particles (Wright, 1930); and Giovanni Lancisi, physician to Pope Clement XI, freed Rome from rinderpest in the early 18th century by using a slaughter policy to prevent infection of unaffected animals (Mantovani and Zanetti, 1993). Thomas Lobb, writing in London in the same century, considered that human plague and rinderpest were caused by particles that multiplied in infected individuals and then infected others, either by contact or through the air (Lobb, 1745). The 18th-century American lexicographer and essayist, Noah Webster, classified diseases as either miasmatic (e.g., pneumonia) or contagious (e.g., smallpox), representing an intermediate stage in the evolution of the contagion theory (Winslow, 1934).

The main advances in the identification of microbes as causes of infectious diseases occurred in the 19th century, although the concept of a living contagious agent, **contagium animatum**, was founded in the 17th century. Edward Jenner's development of a smallpox vaccine using cowpox-infective material (Fisher, 1991), and the proposed use of blankets belonging to smallpox victims as biological weapons against Native American Indians in the 18th century (Ewald, 2000; Brown, 2006), implicitly recognized contagion.

Louis Pasteur's investigation of anthrax and rabies (Walden, 2003), and Robert Koch's discovery of the bacteria causing tuberculosis[11] and cholera (Münch, 2003), firmly established microbiology and marked the downfall of the miasmatic theory. The set of postulates formulated by Koch to define causal agents has been used to identify many microbial diseases since those early days of bacteriology (see Chapter 3).

Viruses also were discovered in the late 19th century, although not actually 'seen' until the invention of the electron microscope in the 1930s. In 1892, Iwanowsky demonstrated that tobacco mosaic disease could be transmitted by sap that had been filtered through bacteria-proof filters (Witz, 1998). Beijerinck serially transmitted the disease using bacteria-free filtrates, and coined the term **contagium vivum fluidum** to describe the infectious 'living' agent. In 1898–1899, Loeffler and Frosch discovered the first animal virus, foot-and-mouth disease virus (Mahy, 2005), and in 1911 Rous reported the first virus-induced transmissible tumour (Weiss and Vogt, 2011).

Towards the end of the 19th century, the first arthropod carrier (a tick) of an infectious disease was identified by Smith and Kilbourne (1893) investigating Texas fever of cattle in the US.

Impetus for change

Changing attitudes towards the cause of disease and the concomitant alterations in techniques of treatment and prevention are a small part of shifts in overall scientific thought. These changes have not taken place gradually, but have occurred as distinct 'revolutions', which terminate periods of stable science (Kuhn, 1970[12]). Each period has its paradigm (model), which serves to guide research. As time passes, anomalies accumulate. Initially, scientists accommodate these by modifying the paradigm, but a time comes when the pressures on the old framework become so great that a crisis occurs, and there is a revolutionary shift

[10] Galen also was an early exponent of preventive medicine, arguing that a good health regimen involved regulation of six 'non-naturals' (air; motion and rest; sleep and waking; food and drink; things excreted; and passions and emotions) (Curth, 2003). The idea was imported into mediæval Europe from Arabian medicine in the 11th century (Porter, 1997).

[11] Anthrax and tuberculosis are diseases of great antiquity, dating back at least to Ancient Egypt, where the former bacterium was most likely the cause of some of the biblical plagues (Manchester, 1984; Blaisdell, 1994; Willcox, 2002; Witowski and Parish, 2002; Sternbach, 2003; Kyriacou *et al*., 2006).

[12] For a critical assessment of Kuhn's philosophy, see Hoyningen-Huene (1993).

in paradigms. For example, in astronomy, the old Ptolemaic model of the universe had to be modified and remodified by adding new planetary epicycles to account for the observed motion of the heavenly bodies, but eventually the critical point was reached when the old model was falling apart under the strain and was ceasing to be credible. Thus, the time was ripe for the dramatic shift in models called the Copernican revolution. Kuhn's thesis also has been applied to political, social and theological 'revolutions' (Macquarrie, 1978) and to the applied sciences (Nordenstam and Tornebohm, 1979) of which veterinary medicine is a part[13].

Veterinary medicine has experienced five stable periods and revolutions up to the middle of the 20th century relating to disease control (Schwabe, 1982), which stimulated the changes in the causal concepts already described. The major problem that persisted during these periods, precipitating crises, was large-scale outbreaks of infectious disease: the classical animal plagues[14] (*Table 1.1*). Military campaigns frequently assisted the spread of these infections (*Table 1.2* and Karasszon, 1988).

The first period: until the first century AD

The initial domestication of animals brought man into close contact with animals and therefore with their diseases. The demonic theory was prevalent. However, despite the use of control techniques consistent with the theory, draft animals continued to die, and a crisis arose when urbanization increased the importance of animals as food resources. This resulted in the development of the first stable phase of veterinary medicine. This was characterized by the emergence of veterinary specialists such as the early Egyptian priest-healers and the Vedic *Salihotriya* who founded the first veterinary hospitals. Humoral pathology developed and the miasmatic theory of cause evolved. Techniques of treatment required careful recognition of clinical signs following the Greek Coan tradition. Quarantine (derived from the Italian word meaning 'forty' – the traditional length, in days, of isolation in the Middle Ages) and slaughter became preventive strategies. These local actions, which lasted until the first century AD, were incapable of solving major problems in the horse, which was becoming an important military animal. This crisis resulted in the second phase: that of military healers.

The second period: the first century AD until 1762

Veterinarians specialized in equine medicine and surgery, reflecting the importance and value of horses (e.g., Richards, 1954). A major veterinary text, the *Hippiatrika*, comprising letters between veterinarians, cavalry officers and castrators, dates from early Byzantine times. The major contributor to this work was Apsyrtus, chief *hippiatros* to the army of Constantine the Great. This phase lasted until the mid-18th century and was marked by a continuing interest in equine matters. Several important texts were written, including Vegetius Renatus' *Ars Veterinaria* (published in 1528) and Carlo Ruini's *Anatomy of the Horse* (published in 1598). Interest was taken in other species, too. The 15th-century *Boke of Saint Albans* described diseases of falcons (Comben, 1969); and John Fitzherbert's *Boke of Husbandrie* (published in 1523) included diseases of cattle and sheep. The horse, however, was pre-eminent. This bias survived in Europe until early in the 20th century, when equine veterinary medicine was still considered to be a more respectable occupation than the care of other species.

During this period, varying emphasis was placed on the miasmatic and metaphysical theories of cause and on humoral pathology. The Arabians, for example, based their medicine largely on the metaphysical theory.

The third period: 1762–1884

The animal plagues, especially those of cattle, became particularly common in Europe in the mid-18th century with the introduction of rinderpest from Asia (Scott, 1996). They provided the next major crisis involving civilian animals. The miasmatic theory persisted but the miasmata were thought to originate from filth generated by man, rather than from natural sources. A third stable phase developed, characterized by improvement of farm hygiene, slaughter and treatment as control techniques. When rinderpest entered England from Holland in 1714, Thomas Bates, surgeon to George I, advocated fumigation of buildings, slaughter and burning of affected animals, and resting of contaminated pasture as typical tactics (Bates, 1717–1719). Cattle owners also were compensated for loss. By the mid-19th century, disinfection (notably

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[13] The concept of dramatic paradigm shifts, however, may not be applicable to all areas of thought and progress. The 17th-century German philosopher, Leibnitz, argued that change (e.g., in ethics and aesthetics) is gradual.

[14] A plague (Greek: *plege* = 'a stroke', 'a blow'; Latin: *plangere* = 'to strike') traditionally is any widespread infectious disease with a high fatality rate among clinically affected individuals. In veterinary medicine, the term is extended to any widespread infectious disease causing major economic disruption, although the fatality rate may not be high (e.g., foot-and-mouth disease). In human medicine, the term is now commonly restricted to infection with the bacterium, *Yersinia (Pasteurella) pestis*: the cause of plague, historically famed as the mediæval Black Death (Bos *et al*., 2011).

Table 1.1 Some dates of occurrence of animal plagues. (Most dates before 1960 are extracted from Smithcors, 1957.)

	Animal plagues						
Date	***Rinderpest***	***Pleuropneumonia***	***Canine distemper***	***Anthrax***	***Foot-and-mouth disease***	***Equine influenza***	***Ill-defined diseases***
500 BC							Egypt 500 BC to time of Christ
							Egypt 278 BC abortion
AD							
				Rome AD 500			Rome fourth century AD (cattle)
							France sixth century AD (cattle)
							Ireland eighth century AD
							France 820, 850, 940–943 (cattle)
							England 1314 (cattle)
AD 1400							
	England 1490*, 1551				Italy 1514		
						England 1688	
AD 1700							
	France 1710–1714	Europe 18th century					
	Rome 1713					England 1727	
	England 1714, 1745–1746					Ireland 1728	
	France 1750		US 1760			England 1733, 1737, 1750,	
			Spain 1761			1760, 1771, 1788	
			England 1763				
AD 1800							
		England 1841–1898			England 1839	England 1837	
	England 1865				England 1870–1872, 1877–1885	North America 1872	
						England 1889–1890	
	Africa 1890–1900						
AD 1900							

(*Continued*)

Table 1.1 (Continued)

	Animal plagues						
Date	***Rinderpest***	***Pleuropneumonia***	***Canine distemper***	***Anthrax***	***Foot-and-mouth disease***	***Equine influenza***	***Ill-defined diseases***
	Belgium 1920				England 1922–1925, 1942,	Czechoslovakia 1957	
					1952, 1967–1968	Britain 1963	
						US 1963	
					Canada 1951–52	Europe 1965	
						Poland 1969	
						USSR 1976	
	Middle East 1969–1970					France, The Netherlands,	
	Africa 1979–1984				Switzerland 1980	Sweden 1978–1979	
	India 1983–1985				Channel Islands, France, Isle	England 1989	
	Turkey 1991–1992				of Wight, Italy, Spain 1981		
					Denmark, Spain 1983		
					Germany (W.), Greece,		
					The Netherlands,		
					Portugal 1984		
					Italy 1985, 1988, 1993		
					India, S. Arabia 1990		
					Nepal 1993–1994		
					Turkey 1995		
					Albania, Bulgaria, Greece,		
					Macedonia, Yugoslavia		
					1996		
					Taiwan 1997		
					Bhutan 1998		
					China 1999		
AD 2000							
					Greece, Japan, Mongolia, S. Africa 2000		
					France, Ireland, The Netherlands, UK 2001		
					UK 2007		
					Japan 2010		
					S. Korea 2010–2011		

* Named as 'steppe murrain' (derivative of Latin *morí* = 'to die').

Table 1.2 Military campaigns that disseminated rinderpest.

Century	*Campaign*
5th	Fall of Rome
8–9th	Charlemagne's conquest of Europe
12th	Genghis Kahn's invasion of Europe
13th	Kublai Kahn's invasion of Europe and China
15–16th	Spanish–Hapsburg conquest of Italy
17th	War of the League of Augsberg
18th	War of the Spanish Succession
18th	War of the Austrian Succession
18th	Seven Years' War
18–19th	Napoleonic Wars
19–20th	US invasion of the Philippines
19–20th	Italian conquest of Eritrea
20th	World War I
20th	World War II
20th	Vietnam War
20th	Lebanese War
20th	Sri Lankan conflict
20th	Azerbaijan conflict
20th	Gulf War

using carbolic and cresylic acids) also was being applied to control the disease (Brock, 2002)[15].

Rinderpest came to particular prominence in Europe in the 18th century (*Figure 1.4*). Half of the cattle in France were destroyed by rinderpest between 1710 and 1714. The disease occurred irregularly until 1750, when it again became a serious problem. Little was known about the disease. This provided impetus for the establishment of the first permanent veterinary school at Lyons in 1762, and others were subsequently founded to combat the disease (*Table 1.3*)[16].

The lifting of animal importation restrictions in England in 1842 increased the risk of disease occurring in Britain. Sheep pox entered Britain in 1847 from Germany, and pleuropneumonia became a serious problem. Public concern, highlighted by the rinderpest outbreak of 1865 (Scott, 1997), was responsible for the establishment of the British State Veterinary Service in the same year. Similar services were founded in other countries. The legislature continued to strengthen the power of the veterinary services by passing Acts relating to the control of animal diseases.

The fourth period: 1884–1960

The animal plagues continued despite sanitary campaigns. This crisis coincided with the inception and acceptance of the microbial theory which, epitomized by Koch's postulates, defined a specific, single cause of an infectious disease and therefore implied a suitable control strategy directed against the causal agent.

This fourth stable phase of campaigns or mass actions began in the 1880s. Treatment of disease was based on laboratory diagnosis involving isolation of agents and identification of lesions followed by therapy. Control of disease by prevention and, subsequently, eradication involved mass testing of animals and immunization when an increasing number of vaccines became available (e.g., canine distemper vaccine: Bresalier and Worboys, 2014)[17]. The discovery of disease vectors facilitated prevention by vector control. An improved understanding of infectious agents' life histories enabled their life-cycles to be broken by manipulating the environment; the draining of land to prevent fascioliasis is a good example. Bacterial diseases remained as major clinical problems until the discovery and synthesis of antibiotics in the 20th century, when, in human medicine, the effectiveness of control measures was starkly reflected in changes in

[15] A notable example of disinfection from human medicine was Ignaz Semmelweis' implementation of a schedule of hand-washing and use of chlorinated lime solutions to reduce the incidence of puerperal fever (Semmelweis, 1861; Carter, 1983). He had noted a clear difference in the frequency of puerperal fever ('childbed fever') in two maternity clinics at the Vienna General Hospital. One clinic (with a low mortality due to the disease) trained midwives, whereas the other (with a higher mortality) trained physicians. He ascribed the difference to the fact that the medical students also conducted post-mortem examinations, after which they transmitted toxic 'decaying animal-organic matter' from the cadavers to the clinic. However, his views were treated with disdain by the medical establishment of the time and led to the term 'Semmelweis reflex' or 'Semmelweis effect' as a metaphor for the reflex-like tendency to reject new evidence or new knowledge because it contradicts established norms, beliefs or paradigms.

[16] There were other pressures, too, fostering the establishment of European veterinary schools. These included the need for military authorities to improve the effectiveness of horse-dependent armies, and the requirement for increased agricultural productivity in the face of population growth (Mathijsen, 1997).

[17] There had been earlier attempts to immunize animals against rinderpest, mimicking the practice of 'variolation' in humans, in which smallpox virus was inoculated to prevent the disease (Weiss and Esparza, 2015). The first such rinderpest trial was undertaken in 1711 by Bernardino Ramazzini at the University of Padua (Koch, 1891). Some authorities believe that the practice of immunization began in China; see Parish (1965), Bazin (2003) and Stern and Markel (2005) for brief histories.

Figure 1.4 Rinderpest in Holland, 1745, Jacobus Eussen, Amsterdam. (Reproduced with permission of Atlas Van Stolk, Rotterdam.)

Table 1.3 Veterinary schools founded to combat rinderpest.

Year of foundation	*City*	*Country*
1762	Lyon	France
1765	Vienna	Austria
1766	Alfort	France
1769	Turin	Piedmont
1773	Copenhagen	Denmark
1777	Giessen	Hesse
1778	Hannover	Hannover

the 'league table' of causes of deaths (*Figure 1.5*). The veterinarian also experienced a similar increase in therapeutic power.

Many infectious diseases were either effectively controlled or eradicated between the latter part of the 19th century and the middle of the 20th century in the more-economically-developed countries using the new techniques of the microbial revolution and older techniques including quarantine, importation restrictions, slaughter and hygiene. In 1892, pleuropneumonia in the US was the first disease to be regionally eradicated after a campaign lasting only five years. Notable British successes included rinderpest, eradicated in 1877, pleuropneumonia in 1898, and glanders and equine parasitic mange in 1928.

Quantification in medicine

The evolution of understanding of the cause of disease purely qualitatively was accompanied by increased interest in disease in quantitative terms. This began primarily as a descriptive exercise. The ancient Japanese reported outbreaks of animal diseases. John Graunt (1662) published quantitative observations on London parish registers and 'Bills of Mortality'. An outbreak of rinderpest in France in the late 18th century was responsible for the establishment of a commission on epidemics, headed by Felix Vicq d'Azyr, Marie Antoinette's personal physician. This evolved into the Royal Society of Medicine, which pioneered the collection of statistical data on animal and human epidemics and the weather (Matthews, 1995).

Post-Renaissance thinking and 'The Enlightenment'

The scientific revolution that began during the 16th century posited that the physical universe was orderly and could be explained mathematically (Dampier, 1948). This argument was extended to the biological world, where it was considered that 'laws of mortality' must exist. Graunt's mortality studies included

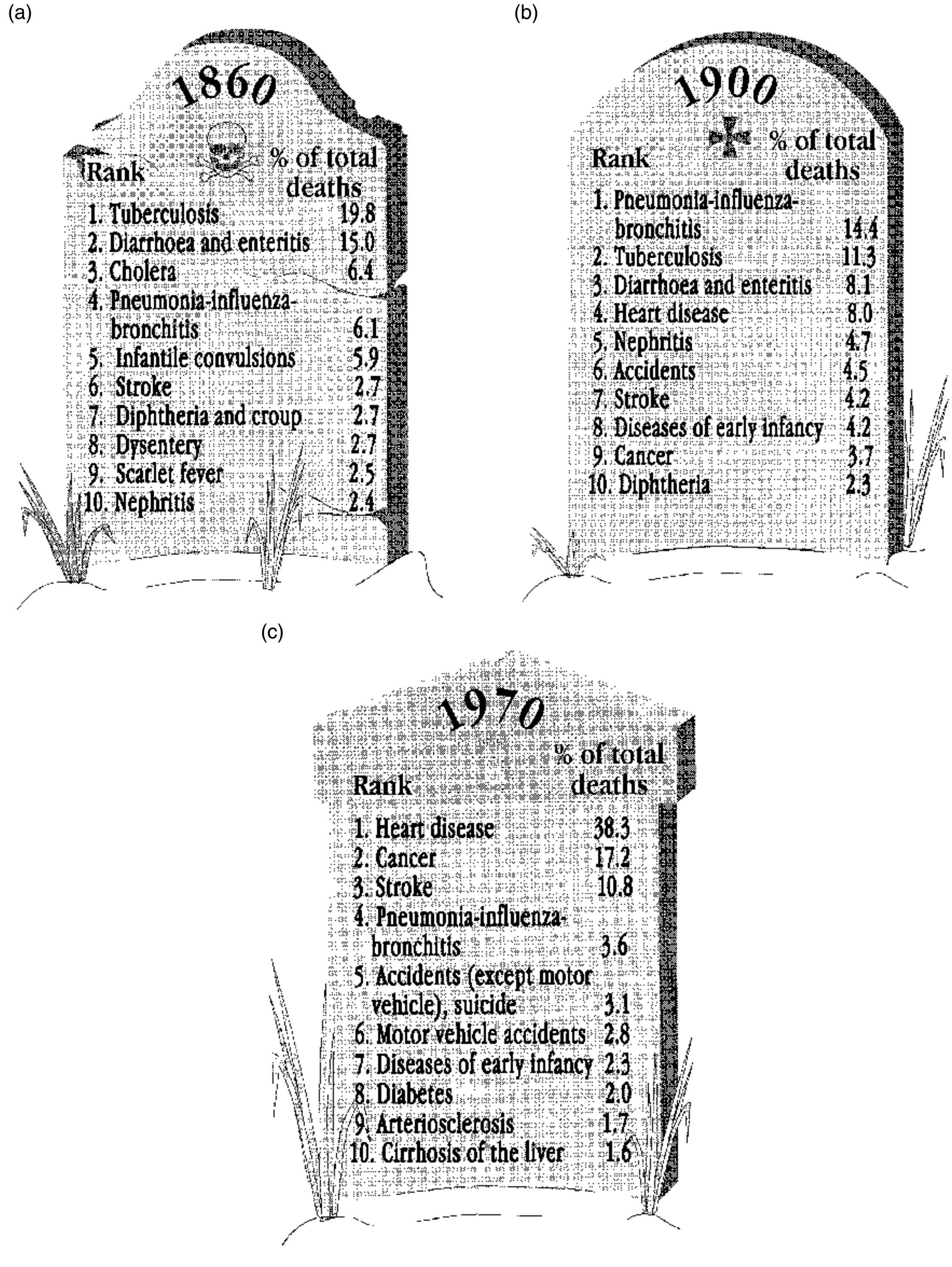

Figure 1.5 League table of causes of human mortality in the UK: (**a**) 1860, (**b**) 1900, (**c**) 1970. (Data from Thrusfield, 2001.)

attempts to formulate such laws by constructing life tables (see Chapter 4); Edmund Halley (1656–1742) constructed life tables for Breslau (Benjamin, 1959); and Daniel Bernoulli (1700–1782) applied life-table methods to smallpox data, thereby demonstrating that inoculation was efficacious in conferring lifelong immunity (Speiser, 1982). A hundred years later, William Farr, the Collator of Abstracts at the Office of the Registrar General in England in the mid-19th century (Halliday, 2000), produced a simple mathematical model of the 1865 rinderpest epidemic in the UK (see Chapter 23).

Quantitative analysis of biological (including medical) phenomena evolved in the 18th century, when the *Age of Enlightenment* saw a growth in literature dealing with the relationship between probability and the need for objectivity in science and society (the 'Probabilistic Revolution'). The mathematical foundation of probability was laid by Jakob Bernoulli in his *Ars Conjectandi*, which was published posthumously in 1713. He developed a theory of 'inverse probability', which stated that the frequency of an event would approach its probability of occurrence if the number of observations was large enough. This theory was mathematically refined by Siméon-Denis Poisson, who proposed a 'law of large numbers', which stated that, if an event was observed a large number of times, one could assume that the probability of its future occurrence would correspond to its observed frequency (Poisson, 1837). The logical consequence of this conclusion is that, if there are sufficient observations, sound predictions can be made. Thus, in relation to therapy, Pierre-Simon Laplace (1814) suggested that a preferred method of treatment '*will manifest itself more and more in the measure that the number (of observations) is increased*'.

A pivotal move towards comparative statistical techniques occurred when Pierre-Charles-Alexander Louis developed his 'numerical method', requiring systematic record keeping and rigorous analysis of multiple cases (Bollett, 1973). He documented typhoid in Paris, showing that the disease occurred predominantly in young adults, and that the average age of fatal cases was higher than that of survivors, suggesting that the younger patients had the best prognosis (Louis, 1836). He subsequently demonstrated that blood-letting was of no benefit to typhoid cases, and his calculation of average values was adopted by other early protagonists of clinical trials (e.g., Joseph Lister; see Chapter 17)[18]. Average values were also applied to provide a quantitative definition of a 'normal' individual; Adolphe Quetelet (1835), for example, recorded the range of the human cardiac and respiratory rates.

Application of probability theory to medicine was cautiously and tendentiously accepted by British and French medical statisticians, who were largely concerned with the descriptive statistics of the major public health issues (e.g., *Figure 1.5*), rather than with statistical inference. Nevertheless, during the 19th century, strong links were forged between epidemiologists, mathematicians and statisticians through the common influence of Louis (Lilienfeld, 1979)[19], and, by the 20th century, rigorous methods of statistical inference were developing (Stigler, 1986) and were being applied in medicine and agriculture. These methods necessitate observation of events in populations, rather than in the individual, and are thus central to the development of quantitative epidemiology (see Chapter 2).

The formulation of physical and biological events, however, now, as then, needs to be very carefully assessed, and may convey an illusion of certainty and security that is not warranted (Gupta, 2001). Moreover, it is not always considered to be socially beneficial[20], and is not a substitute for rigorous, albeit sometimes onerous, analysis of field data (*The Economist*, 2002). Additionally, there may be a tendency to use whatever numerical data are available, regardless of their relevance and quality (Gill, 1993; Wang *et al.*, 2013)[21].

Contemporary veterinary medicine

Current perspectives

Infectious diseases

Although there have been notable successes in the control of the infectious diseases, some still pose problems in both more-economically-developed and less-economically-developed countries (*Table 1.4*), and some continue to recur; for example, foot-and-mouth disease (*Table 1.5*), which erupted in Western Europe with devastating consequences (notably in the UK) in

[18] The application of statistical methods in medicine by Louis, however, was not without its contemporary critics (Fernández-Guerrero *et al.*, 2014).

[19] An interesting 'family tree', showing the links between 18th–20th-century statisticians, public health physicians and epidemiologists, is depicted by Lilienfeld and Lilienfeld (1980).

[20] See, for example, Gregory (2002) for a brief theological discussion.

[21] Chambers (1997) amalgamates Gupta's and Gill's points, with sights set particularly on economists: '*Quantification and statistics can mislead, distract, be wasteful, simply not make sense or conflict with common values…Yet professionals, especially economists and consultants tight for time, have a strong felt need for statistics. At worst they grub around and grab what numbers they can, feed them into their computers and print out not just numbers, but more and more elegant graphs, bar charts, pie charts and three-dimensional wonders…Numbers can also reassure by appearing to extend control, precision and knowledge beyond their real limits…wrong numbers, one might add, are worst of all because all numbers pose as true.*' Porter (1995) provides a philosophical discussion of quantification in general.

Table 1.4 Current trends in the distribution of some infectious diseases of animals. (Extracted mainly from Mulhern *et al*., 1962; Knight, 1972; Blaha, 1989; West, 1995; and Radostits *et al*., 1999.)

Disease	*Host*	*Trends*
Anthrax	All animals, particularly devastating in cattle	Worldwide range, now contracting to mainly tropics and sub-tropics
Aujeszky's disease	Pigs	Spreading
Bluetongue	Sheep and other ruminants	Spreading for past 100 years
Bovine brucellosis	Cattle	Eradicated from many of the more-economically-developed countries
Contagious bovine pleuropneumonia	Cattle	Eradicated from Europe
Glanders	Horses	Mostly eradicated from the more-economically-developed countries
Johne's disease	Cattle, sheep, goats	Worldwide distribution with increasing prevalence in some countries, and spreading in Europe
Lumpy skin disease	Cattle	Extending from Africa to the Middle East
Rabies	All mammals, some birds	Eradication is problematic. Geographically isolated areas (including some island masses) are generally free, although most countries experience rabies to some extent
Rift Valley fever	Cattle, sheep, goats, man	Extending from Africa to the Middle East
Rinderpest	Artiodactyls	Declared eradicated globally in 2011
Sheep pox	Sheep	Eradicated from Europe in 1951. Present in Africa, the Middle East and India
Swine vesicular disease	Pigs	Decreased significance since 1982
Tuberculosis	Many species, especially serious in cattle	Eradication has proved problematic but some success has been achieved

Table 1.5 Number of outbreaks of foot-and-mouth disease in the UK, 1892–2016.

Year	*Outbreaks*	*Year*	*Outbreaks*	*Year*	*Outbreaks*	*Year*	*Outbreaks*
1892	95	1919	75	1939	99	1959	45
1893	2	1920	13	1940	100	1960	298
1894	3	1921	44	1941	264	1961	103
1895	0	1922	1140	1942	670	1962	5
1896–1899	0	1923	1929	1943	27	1963–1964	0
1900	21	1924	1	1944	181	1965	1
1901	12	1925	260	1945	129	1966	34
1902	1	1926	204	1946	64	1967	2210
1903–1907	0	1927	143	1947	104	1968	187
1908	3	1928	138	1948	15	1969–1980	0
1909	0	1929	38	1949	15	1981	1
1910	2	1930	8	1950	20	1982–2000	0
1911	19	1931	97	1951	116	2001	2030
1912	83	1932	25	1952	495	2002–2006	0
1913	2	1933	87	1953	40	2007	8
1914	27	1934	79	1954	12	2008–2016	0
1915	56	1935	56	1955	9		
1916	1	1936	67	1956	162		
1917	0	1937	187	1957	184		
1918	3	1938	190	1958	116		

Table 1.6 Some emergent infectious diseases and plagues of animals in the 20th century.

Year	*Country*	*Infection*	*Source*
1907	Kenya	African swine fever	Montgomery (1921)
1910	Kenya	Nairobi sheep disease	Montgomery (1917)
1918	US	Swine influenza	Shope (1931)
1929	South Africa	Lumpy skin disease	Thomas and Maré (1945)
1929	US	Swine pox	McNutt *et al.* (1929)
1930	US	Eastern equine encephalomyelitis	Kissling *et al.* (1954)
1930	US	Western equine encephalomyelitis	Kissling (1958)
1932	US	Vesicular exanthema of pigs	Traum (1936)
1933	Iceland	Maedi-visna	Sigurdsson (1954)
1939	Colombia	Venezuelan equine encephalomyelitis	Kubes and Rios (1939)
1946	Canada	Mink enteritis	Schofield (1949)
1947	US	Transmissible mink encephalopathy	Hartsough and Burger (1965)
1953	US	Bovine mucosal disease	Ramsey and Chivers (1953)
1955	US	Infectious bovine rhinotracheitis	Miller (1955)
1956	Czechoslovakia	Equine influenza A (H7N7)	Bryans (1964)
1962	France	West Nile equine encephalomyelitis	Panthier (1968)
1963	US	Equine influenza A (H3N8)	Bryans (1964)
1966	UK	Bovine ulcerative mammillitis	Martin *et al.* (1966)
1972	Iran	Camel pox	Baxby (1972)
1972	US	Lyme disease	Steere *et al.* (1977)
1974	Kenya	Horsepox	Kaminjolo *et al.* (1974)
1975	South Africa	Haemorrhagic Rift Valley fever	Van Velden *et al.* (1977)
1977	Worldwide	Canine parvovirus	Eugster *et al.* (1978)
1977	USSR	Cat pox	Marennikova *et al.* (1977)
1980	UK	Infectious bursitis-2	McFerran *et al.* (1980)
1981	Zimbabwe	Mokola virus infection	Foggin (1983)
1983	US	Fulminating avian influenza (H5N2)	Buisch *et al.* (1984)
1985	Denmark	Danish bat rabies (Duvenhage)	Grauballe *et al.* (1987)
1986	UK	Bovine spongiform encephalopathy	Wells *et al.* (1987)
1986	US	Cache Valley teratogenesis	Chung *et al.* (1991)

2001 (*Table 1.1*). Some have emerged as major problems this century, although there is circumstantial evidence that the infectious agents have existed for some time (*Table 1.6*). Others are apparently novel (*Table 1.7*)[22]. Military conflict continues to be responsible for spreading these diseases (*Table 1.2*); for example, at the end of the Second World War, retreating Japanese soldiers brought rinderpest from Myanmar (Burma) to north-eastern Thailand.

[22] Emergent and novel infectious diseases may be classified together as 'emerging diseases': '*… infections that have newly appeared in a population or have existed but are rapidly increasing in incidence or geographic range*' (Morse, 1995). Alternatively, emerging diseases can also be categorized as either 'newly emerging' or 're-emerging', the former being recognized in a host for the first time, and the latter comprising historical infections that continue to appear in new locations or in drug-resistant forms, or that reappear after apparent control (Fauci and Morens, 2012); but the complicated nature of many emerging infections often leaves their classification debatable (Morens and Fauci, 2013). Infectious diseases may emerge either as a result of genetic changes in infectious agents or their hosts (see Chapter 5) or following ecological changes (see Chapter 7). Schrag and Wiener (1995) conclude that both ecological and genetic evolutionary changes can contribute to the emergence of infectious diseases, but that ecological change is probably the more general explanation for new epidemics (probably because ecological changes are less constrained than evolutionary changes in hosts and pathogens). The emergence of exclusively human pathogens also may be the last stage in transformation from animal pathogens (Wolfe *et al.*, 2007).

Table 1.7 Some novel infectious diseases and plagues of animals in the 20th and 21st centuries.

Year	*Country*	*Infection*	*Source*
1907	Hungary	Marek's disease	Marek (1907)
1912	Kenya	Rift Valley fever	Daubney *et al.* (1931)
1923	The Netherlands	Duck plague	Baudet (1923)
1925	US	Avian laryngotracheitis	May and Tittsler (1925)
1926	Java	Newcastle disease	Doyle (1927)
1928	France	Feline panleukopenia	Verge and Cristoforoni (1928)
1930	US	Avian encephalomyelitis	Jones (1932)
1930	US	Avian infectious bronchitis	Schalk and Hawn (1931)
1932	US	Equine virus abortion	Dimock and Edwards (1932)
1937	US	Turkey haemorrhagic enteritis	Pomeroy and Fenstermacher (1937)
1942	Ivory Coast	Goat plague (peste des petits ruminants)	Gargadennec and Lalanne (1942)
1945	US	Duck virus hepatitis-1	Levine and Fabricant (1950)
1945	US	Transmissible gastroenteritis of pigs	Doyle and Hutchings (1946)
1946	US	Bovine virus diarrhoea	Olafson *et al.* (1946)
1946	US	Aleutian disease of mink	Hartsough and Gorham (1956)
1947	Sweden	Infectious canine hepatitis	Rubarth (1947)
1950	US	Avian adenovirus-1	Olson (1950)
1951	US	Turkey bluecomb disease	Peterson and Hymas (1951)
1953	US	Feline infectious anaemia	Flint and Moss (1953)
1954	Japan	Akabane disease	Miura *et al.* (1974)
1954	Canada	Avian reovirus	Fahey and Crawley (1954)
1956	China	Goose plague	Fang and Wang (1981)
1957	US	Feline calicivirus	Fastier (1957)
1958	US	Feline viral rhinotracheitis	Crandell and Maurer (1958)
1959	Canada	Turkey viral hepatitis	Mongeau *et al.* (1959)
1959	Japan	Ibaraki disease	Omori *et al.* (1969)
1960	Israel	Turkey meningoencephalitis	Komarov and Kalmar (1960)
1962	US	Bovine adenovirus-1,2	Klein (1962)
1962	US	Avian infectious bursitis-1	Cosgrove (1962)
1964	UK	Feline leukaemia	Jarrett *et al.* (1964)
1964	UK	Porcine adenovirus	Haig *et al.* (1964)
1965	UK	Duck virus hepatitis-2	Asplin (1965)
1965	US	Canine herpes	Carmichael *et al.* (1965)
1965	US	Porcine enteroviruses	Dunne *et al.* (1965)
1966	Italy	Swine vesicular disease	Nardelli *et al.* (1968)
1967	UK	Porcine parvovirus	Cartwright and Huck (1967)
1967	UK	Border disease in sheep	Dickinson and Barlow (1967)
1967	US	Chronic wasting disease of deer	Williams and Young (1980)
1968	Canada	Bovine adenovirus-3	Darbyshire (1968)
1969	US	Duck virus hepatitis-3	Toth (1969)
1972	UK	Lymphoproliferative disease of turkeys	Biggs *et al.* (1974)
1973	US	Equine adenovirus	McChesney *et al.* (1973)

(*Continued*)

Table 1.7 (Continued)

Year	*Country*	*Infection*	*Source*
1974	US	Feline herpes urolithiasis	Fabricant and Gillespie (1974)
1974	US	Caprine arthritis-encephalitis	Cork *et al*. (1974)
1974	Japan	Kunitachi virus	Yoshida *et al*. (1977)
1976	The Netherlands	Egg-drop syndrome	Van Eck *et al*. (1976)
1976	Japan	Avian infectious nephritis	Yamaguchi *et al*. (1979)
1977	US	Chicken parvovirus	Parker *et al*. (1977)
1977	Ireland	Contagious equine metritis	O'Driscoll *et al*. (1977)
1978	Iraq	Pigeon paramyxovirus-1	Kaleta *et al*. (1985)
1979	Japan	Chick anaemia agent	Yuasa *et al*. (1979)
1981	US	Canine calicivirus	Evermann *et al*. (1981)
1984	China	Rabbit haemorrhagic disease	Liu *et al*. (1984)
1985	US	Potomac horse fever	Rikihisa and Perry (1985)
1985	UK	Rhinotracheitis of turkeys	Anon. (1985)
1985	Japan	Chuzon disease of cattle	Miura *et al*. (1990)
1987	USSR	Phocid distemper-2 (Baikal)	Grachev *et al*. (1989)
1987	US	Porcine reproductive and respiratory syndrome	Keffaber (1989)
1987	US	Morbillivirus of dolphins	Lipscomb *et al*. (1994)
1988	The Netherlands	Phocid distemper-1 (North Sea)	Osterhaus and Vedder (1988)
1990	The Netherlands	Bovine birnavirus	Vanopdenbosch and Wellemans (1990)
1994	Australia	Hendra virus (formerly equine morbillivirus)	Murray *et al*. (1995)
1995	New Zealand	Wobbly possum disease virus	Anon. (1997)
1996	US	Porcine wasting disease syndrome	Daft *et al*. (1996)
2003	Taiwan	Herpes-like virus of abalone	Chang *et al*. (2005a)
2011	Germany	Schmallenberg virus	Hoffman *et al*. (2012)
2012	US	Canine circovirus	Kapoor *et al*. (2012)

The infectious diseases are particularly disruptive in the less-economically-developed countries, where more than half of the world's livestock are located (*Table 1.8*), accounting for over 80% of power and traction (Pritchard, 1986) and, in pastoral communities, at least 50% of food and income (Swift, 1988) (with milk, alone, accounting for up to 75% of human daily energy requirements: Field and Simkin, 1985). There have been some successes, for example, the JP15 campaign against rinderpest in Africa (Lepissier and MacFarlane, 1966) and, despite setbacks to this campaign caused by civil strife and complacency (Roeder and Taylor, 2002), the disease was declared globally eradicated in 2011 (FAO/OIE, 2011). Several vector-transmitted diseases with complex life-cycles, including haemoprotozoan infections such as trypanosomiasis, have not been controlled satisfactorily[23]. The techniques of the microbial revolution have enabled these diseases to be identified, but accurate means of assessing their extent and distribution also are necessary in order to plan control programmes.

[23] The reasons for lack of progress in the control of animal diseases in less-economically-developed countries are complex, including more than lack of technical feasibility. Insufficient applied research to solve field problems, poor information, and neglect of farmers' needs and the requirement for farmer participation in disease control, all contribute to the problem (Huhn and Baumann, 1996; Bourn and Blench, 1999). With the demand for livestock products in less-economically-developed countries estimated to double by 2020 (Delgado *et al*., 1999), the supply of livestock services, including veterinary services, is likely to increase in importance, and issues such as privatization (Holden *et al*., 1996; Ahuja, 2004) and delivery to the poor (Ahuja and Redmond, 2004) will require close scrutiny.

Table 1.8 World livestock populations, 2011 (1000s of animals). (From FAO: faostat.fao.org/site/573/default.aspx#ancor; accessed 16 August 2013.)

	Cattle	*Sheep*	*Goats*	*Pigs*	*Horses*	*Chickens*	*Buffaloes*	*Camels*
North America	104 838	6 379	3 026	79 146	10 556	2 244 690	–	–
Central America	46 940	8 875	9 196	20 530	7 273	659 892	–	–
South America	350 960	73 149	22 155	62 383	15 051	2 190 251	1 279	–
Europe	121 263	127 532	17 281	187 536	5 829	2 039 218	390	7
Africa	276 361	304 671	321 353	32 205	6 104	1 732 180	3 800	22 684
Asia	477 541	466 059	542 366	576 632	13 755	11 513 988	189 922	3 944
Oceania	39 261	104 247	4 917	5 178	395	116 094	210	–
All parts of the world	1 426 389	1 093 566	924 146	967 165	58 472	20 708 000	195 397	26 635

Some infectious diseases, for example, brucellosis and tuberculosis, persist at low levels in the more-economically-developed countries, despite the application of traditional control methods. This problem can result from inadequate survey techniques and insensitive diagnostic tests (Martin, 1977). In some cases, an infectious agent may have a more complex natural history than initially suspected. For example, continued outbreaks of bovine tuberculosis in problem herds in England (Wilesmith *et al*., 1982) have been shown to be associated with pockets of infection in wild badgers (Little *et al*., 1982; Krebs, 1997), which has resulted in a somewhat contentious control strategy of badger culling (Donnelly *et al*., 2003; DEFRA, 2004; Grant, 2009).

The effective control of the major infectious diseases has allowed an increase in both animal numbers (*Table 1.9*) and productivity (*Table 1.10*) in the more-economically-developed countries (mechanization making draft horses the exception)[24]. There generally has been an increase in the size of herds and flocks, notably in dairy, pig (*Table 1.11*) and poultry enterprises. Intensification of animal industries is accompanied by changes in animal health problems.

Complex infectious diseases

The animal plagues are caused by 'simple' agents, that is, their predominant causes can be identified as single infectious agents. Diseases caused by single agents still constitute problems in the more-economically-developed countries. Examples include salmonellosis, leptospirosis, babesiosis and coccidiosis. However, diseases have been identified that are produced by simultaneous infection with more than one agent (mixed infections), and by interaction between infectious agents and non-infectious factors. These are common in intensive production enterprises. Diseases of the internal body surfaces – enteric and respiratory diseases – are particular problems. Single agents alone cannot account for the pathogenesis of these complex diseases.

Subclinical diseases

Some diseases do not produce overt clinical signs although they often affect production. These are called **subclinical** diseases. Helminthiasis and marginal mineral deficiencies, for example, decrease rates of liveweight gain. Porcine adenomatosis decreases growth in piglets, although there may be no clinical signs (Roberts *et al*., 1979). Infection of pregnant sows with porcine parvovirus in early pregnancy destroys fetuses, the only sign being small numbers of piglets in litters (Mengeling, 2006). These diseases are major causes of production loss; their identification often requires laboratory investigations.

Non-infectious diseases

Non-infectious diseases have increased in importance following control of the major infectious ones. They can be predominantly genetic (e.g., canine hip dysplasia), metabolic (e.g., bovine ketosis) or neoplastic (e.g., canine mammary cancer). Their cause may be

[24] Some earlier improvements in productivity had occurred as a consequence of improved nutrition. For example, in England in the 18th century, more land was planted with high-yielding roots (e.g., turnips) and new types of grass, enabling animals to be fed adequately throughout the year. The average weight of an ox at London's Smithfield Market increased from 370 lb in 1710 to 800 lb in 1795 (Paston-Williams, 1993). Additionally, in the 19th century, crop yields were increased further by the development of fertilizers (Sneddon, 2014), and livestock feed conversion and weight gain were boosted in the 20th century by the use of growth promoters (Lawrence, 1998). The demand for increased livestock production is historically linked to human population growth, rising incomes and urbanization, although future trends are likely to be affected by competition for natural resources (notably, land and water), socio-economic factors (e.g., environmental and animal-welfare legislation) and carbon constraints (Thornton, 2010).

Table 1.9 The livestock population of Great Britain, 1866–2012 (1000s of animals). (From HMSO, 1968, 1982, 1991, 1998; DEFRA, 2012c.)

Year	*Cattle*	*Sheep*	*Pigs*	*Horses (agricultural use)*	*Fowls*	*Turkeys*
1866	4 786	22 048	2 478	–	–	–
1900	6 805	26 592	2 382	1 078	–	–
1925	7 368	23 094	2 799	910	39 036	730
1950	9 630	19 714	2 463	347	71 176	855
1965	10 826	28 837	6 731	21	101 956	4 323
1980	11 919	30 385	7 124	–	115 895	6 335
1989	10 510	38 869	7 391	–	121 279	–
1997	9 902	39 943	7 375	–	111 566*	–
2012†	9 900	32 215	4 281	–	102 558	3 747

– Data not available.
* 1995 figure. (A new approach to collecting poultry information began in 1997, preventing direct comparisons with previous years.)
† Data for 2012 collected in a different manner to previous years, preventing direct comparison.

Table 1.10 World cattle productivity, 2011. (From FAO: faostat.fao.org/site/569/default.aspx#ancor, accessed 16 August 2013.)

	Number of animals slaughtered (1000s of animals)	*Carcass weight (kg/animal)*	*Milk yield (kg/animal)*	*Milk production (1000s metric tonnes)*
US	35 108	341	9 678	89 015
South America	64 492	225	1 780	65 597
Asia	89 089	154	1 631	168 396
Africa	35 345	152	533	31 171
Europe	43 517	247	5 520	208 986
Oceania	12 135	227	4 192	27 065
All parts of the world	295 828	212	2 363	614 579

associated with several factors; for example, feline urolithiasis is associated with breed, sex, age and diet (Willeberg, 1977).

Some conditions, such as ketosis, are particularly related to increased levels of production; ketosis is more likely in cows with high milk yields than in those with low yields. Intensive production systems may also be directly responsible for some conditions; for example, foot lesions in individually-caged broilers (Pearson, 1983).

Diseases of unknown cause

The cause of some diseases has not been fully elucidated, despite intensive experimental and field investigations over many years. Examples include the related diseases feline dysautonomia (Edney *et al*., 1987; Nunn *et al*., 2004) and equine grass sickness (Hunter *et al*., 1999; McCarthy *et al*., 2001; Wlaschitz, 2004).

In some situations, infectious agents have been isolated from cases of a disease but cannot be unequivocally associated with the disease. An example is *Mannheimia haemolytica* (previously named *Pasteurella haemolytica*) in relation to 'shipping fever' (Martin *et al*., 1982). This syndrome occurs in cattle soon after their arrival at feedlots. Post-mortem examination of fatal cases has revealed that fibrinous pneumonia is a common cause of death. Although *M. haemolytica* frequently is isolated from lungs, it is not invariably present. Attempts to reproduce the disease experimentally are fraught with problems, not the least of which is the difficulty of establishing colonization of the nasal tract with the bacterium (Whiteley *et al*., 1992). Other factors also seem to be involved (Radostits *et al*., 2007). These include mixing animals and then penning them in large groups, the feeding of corn silage, dehorning, and,

Table 1.11 Pig herd structure in England and Wales (June)*. (Data supplied by the Meat and Livestock Commission and BPEX.)

	1965	*1971*	*1975*	*1980*	*1991*	*1999*	*2005*†	*2012*†
Number of farms with pigs	94 639	56 900	32 291	22 973	13 738	10 460	7 560	7 860
Total sows (1000s)	756.3	791.0	686.0	701.1	672.4	580.5	384.2	351.2
Average herd size (sows)	10.4	18.5	27.6	41.4	70.4	86.3	81.4	79.3
Number of herds by herd								
size (sows):								
1–49	56 560 (75.4%)	39 000 (90.9%)	20 873 (84.0%)	12 900 (76.3%)	6 471 (67.8%)	4 714 (70.1%)	1 972 (41.8%)	2 203 (49.8%)
50–99	10 445 (13.9%)	2 700 (6.3%)	2 401 (9.7%)	2 000 (11.8%)	1 050 (11.0%)	522 (7.8%)	1 201 (25.5%)	1 072 (24.2%)
100–199	8 034 (10.7%)	1 000 (2.3%)	1 141 (4.6%)	1 300 (7.7%)	1 115 (11.7%)	581 (8.6%)	700 (14.8%)	458 (10.3%)
200 and over	–	200 (0.5%)	426 (1.7%)	700 (4.1%)	914 (9.5%)	911 (13.5%)	845 (17.9%)	693 (15.7%)
Total number of herds with sows	75 039	42 900	24 841	16 900	9 550	6 728	4 718	4 426

* The methodology for the June survey has changed. Figures are now only collected from 'commercial' holdings. Commercial holdings are those with significant levels of farming activity. These significant levels are classified as any holding with one or more of the following: more than five hectares of agricultural land, one hectare of orchards, 0.5 hectares of vegetables or 0.1 hectares of protected crops, or more than 10 cows, 50 pigs, 20 sheep, 20 goats or 1000 poultry. Therefore, figures for 2005 and 2012 are not directly comparable with those for previous years, which would have included non-commercial holdings.

† Figures are for England only. Of the numbers quoted, published figures for Wales now only give the total number of farms with pigs (810 in 2005 and 1410 in 2012) and the total number of sows (3900 in 2005 and 4900 in 2012).

paradoxically, vaccination against agents that cause pneumonia, including *M. haemolytica* – factors associated with adrenal stress (see *Figure 3.6b* and Chapter 5).

Management and environment also appear to play significant, although often not clearly defined, roles in other diseases. Examples include enzootic pneumonia and enteritis in calves (Roy, 1980), enteric disease in suckling pigs, porcine pneumonia, bovine mastitis associated with *Escherichia coli* and *Streptococcus uberis* (Blowey and Edmondson, 2000) and mastitis in intensively housed sows (Muirhead, 1976).

In some instances, the infectious agents that are isolated are ubiquitous and also can be isolated from healthy animals, for example, enteric organisms (Isaacson *et al*., 1978). These are 'opportunistic' pathogens, which cause disease only when other detrimental factors are also present.

In all of these cases, attempts to identify a causal agent fulfilling Koch's postulates frequently fail, unless unnatural techniques, such as abnormal routes of infection and the use of gnotobiotic animals, are applied.

The fifth period

The animal health problems and anomalies that emerged in the 20th century stimulated a change, which began in the 1960s, in attitude towards disease causality and control.

Causality

The inappropriateness of Koch's postulates as criteria for defining the cause of many syndromes suggested that more than one factor may sometimes operate in producing disease. A **multifactorial** theory of disease has developed, equally applicable to non-infectious and infectious diseases. Interest in human diseases of complex and poorly understood cause grew in the early years of the 20th century (Lane-Claypon, 1926) and was responsible for the development of new methods for analysing risk factors, for example smoking in relation to lung cancer (Doll, 1959), and these epidemiological techniques are now firmly established in veterinary medicine, too (e.g., in the investigation of risk factors for respiratory disease in pigs: Stärk, 2000).

There is also now awareness that the causes of disease include social, geographical, economic and political factors, as well as biological and physical ones (Hueston, 2001). For instance, although bovine spongiform encephalopathy subsequently spread to mainland Europe, its initial emergence in the UK (*Table 1.6*) was the result of recycling infective meat and bone meal to cattle, and this practice was extensive because meat and bone meal was an inexpensive source of high-quality protein in cattle rations in a country that had heavily intensified and in which plant proteins were limited. Likewise, bovine tuberculosis is a manifest and expanding problem in white-tailed deer in north-eastern Michigan in the US because the deer populations have increased as a result of feeding programmes established to serve the hunting industry that has replaced cattle farming in this economically deprived area.

New control strategies

Two major strategies have been added to the earlier techniques (Schwabe, 1980a,b):

1. the structured recording of information on disease;
2. the analysis of disease in populations.

These methods involve two complementary approaches: the continuous collection of data on disease – termed **surveillance** and **monitoring** – and the intensive investigation of particular diseases. A further technique, used at the individual farm level, is the recording of information on both the health and productivity of each animal in a herd, as a means of improving production by improving herd health.

Recent trends

Several recent trends have occurred in relation to the services that the veterinarian supplies to his or her clients, and to national and international disease reporting.

Veterinary services

Veterinarians practising in the livestock sector continue to control and treat disease in individual animals. Developments in molecular biology are improving diagnostic procedures (Buckingham, 2011), and offer new opportunities for vaccine production (Report, 1990). Additionally, in intensive production systems, the multifactorial nature of many diseases necessitates modification of the environment of the animal and management practices, rather than concentrating exclusively on infectious agents.

Diseases of food animals also are being considered directly in relation to their effect on **production**. Reduced levels of production can be used as 'diagnostic indicators'; for example, small litter size as an indicator of infection with porcine parvovirus. More significantly, veterinary emphasis has shifted from disease as a clinical entity in the individual animal to disease assessed in terms of suboptimal health, manifested by decreased herd performance: disease is being defined as the unacceptable performance of **groups** of animals. There is thus a need to identify all factors that contribute to the occurrence of disease, to select suitable 'performance indicators' (e.g., 'calving to conception interval'), and to define targets for these indicators in herds under a particular system of husbandry. It is then possible to identify those herds that miss the targets. This is called **performance-related diagnosis** (Morris, 1982), and includes not only the measurement of overt indicators, such as liveweight gain, but also estimation of covert biochemical values, such as metabolite levels in serum. Thus, clinical disease, subclinical disease and production need to be monitored in the context of anticipated ('normal') levels for a particular production system (Dohoo, 1993).

The veterinarian therefore has become more involved in husbandry, management and nutrition than previously, and less involved in traditional 'fire brigade' treatment of clinically sick animals. However, the livestock owner frequently still regards the veterinarian solely as a dispenser of treatment (Goodger and Ruppanner, 1982), relying on feed representatives, dairy experts and nutritionists for advice on breeding, nutrition and management. The extent of this problem varies from one country to another, but indicates that the veterinarian's evolving role in animal production requires a change not only in veterinary attitudes but also sometimes in those of animal owners[25].

Government veterinary services, too, are becoming increasingly concerned with investigations of specific animal health problems of complex cause, such as mastitis, thereby extending their role beyond the traditional control of mass infectious diseases.

As the mass infectious diseases are controlled, and animal production becomes more intensive, other diseases become relatively more important. They are currently major problems in the more-economically-developed countries and in some less-economically-developed countries that have intensive enterprises, such as poultry and pig units in Malaysia, the Philippines and Taiwan. These diseases will become increasingly significant in the less-economically-developed countries when the mass infectious diseases are controlled.

[25] Inertia in veterinary attitudes towards preventive medicine is well-documented (Woods, 2013a; Ruston *et al*., 2016).

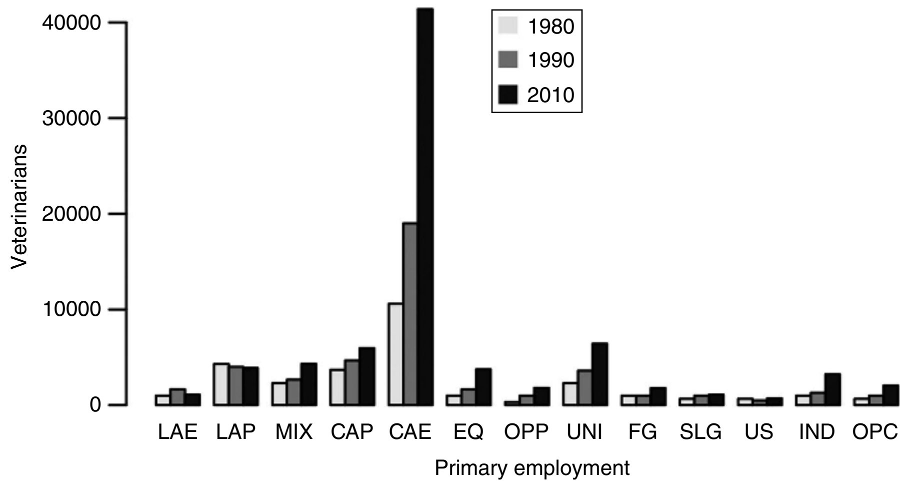

Figure 1.6 Areas of employment of veterinarians in the US, 1980, 1990 and 2010. LAE: exclusively large animal; LAP: predominantly large animal; MIX: mixed practice; CAP: predominantly companion animal; CAE: exclusively companion animal; EQ: equine; OPP: other private practice; UNI: university; FG: federal government; SLG: state or local government; US: uniformed services; IND: industry; OPC: other public and corporate. (Source: Wise and Yang, 1992 and AVMA, 2013. Reproduced with permission of the American Veterinary Medical Association.)

The 20th century saw a turn towards companion-animal practice, particularly in the more-economically-developed countries (e.g., Heath, 1998)[26]. In the UK, for example, this trend began in the inter-war years, influenced by increasing wealth and the rise of lay animal-welfare charities (Gardiner, 2014). This continues to be reflected in the employment trends in the veterinary profession (*Figure 1.6*). Many health problems of companion animals are complex too, and a full understanding of their cause and control is possible only when the contribution of genetic and environmental factors is appreciated. Examples include urinary tract infections in bitches, in which concurrent disease and recent chemotherapy are important factors (Freshman *et al*., 1989), and equine colic, which is related to age and breed (Morris *et al*., 1989; Reeves *et al*., 1989). Problems of veterinary interest now extend beyond clinical conditions to wider social issues, such as the biting of children by dogs (Gershman *et al*., 1994) and animal welfare (see later in this chapter).

Additionally, veterinary services have an enlarging responsibility for human health, including preventing and controlling emerging zoonotic diseases, and addressing antibiotic resistance (an area of endeavour that has been traditionally labelled **veterinary public health**), and protecting the environment and ecosystems (Chomel, 1998; Marabelli, 2003; Pappaioanou, 2004).

Food quality

A particular area of concern in veterinary public health is food quality. The public's concern about what it consumes is not new (*Figure 1.7*). However, during the last two decades of the 20th century, concern increased because of major outbreaks of foodborne infections of animal origin (Cohen, 2000). Examples include an outbreak of salmonellosis affecting over 200 000 people in the US in 1994, and *Escherichia coli* O157:H7 infection affecting over 6000 schoolchildren in Japan in 1996 (WHO, 1996). Other emerging foodborne pathogens include *Cryptosporidium* and *Campylobacter* spp. (Reilly, 1996) and *Listeria monocytogenes* (WHO, 1996). Additionally, the emergence of bovine spongiform encephalopathy, with its putative role as the cause of the fatal human disease, variant Creutzfeldt–Jakob disease (Will, 1997), served to heighten public concern over food safety. In several Western countries, this has led to the establishment of Food Standards Agencies whose remit is to oversee food quality.

The veterinarian's role is now extended beyond guaranteeing wholesomeness of food at the abattoir, and addresses all levels of the production chain, from the farm to the table ('from paddock to plate') (Smulders and Collins, 2002, 2004). This necessitates the establishment of quality assurance programmes both on the farm and throughout the food chain, using techniques such as HACCP (Hazard Analysis Critical Control Points) (Noordhuizen, 2000; Arvanitoyannis, 2009), thus marking a shift in focus from herd health, alone, to quality control of food throughout the production chain (*Figure 1.8*). This approach is strengthened by quantitative evaluation of the risk of transmission of infection throughout the chain (see Chapters 2 and 24).

Animal welfare

The attitude of the public to animals, notably in the more-economically-developed countries, is reflected

[26] In many less-economically-developed countries, private veterinary practice remains a minority employer of veterinarians, with companion animals of little significance (e.g., Turkson, 2003).

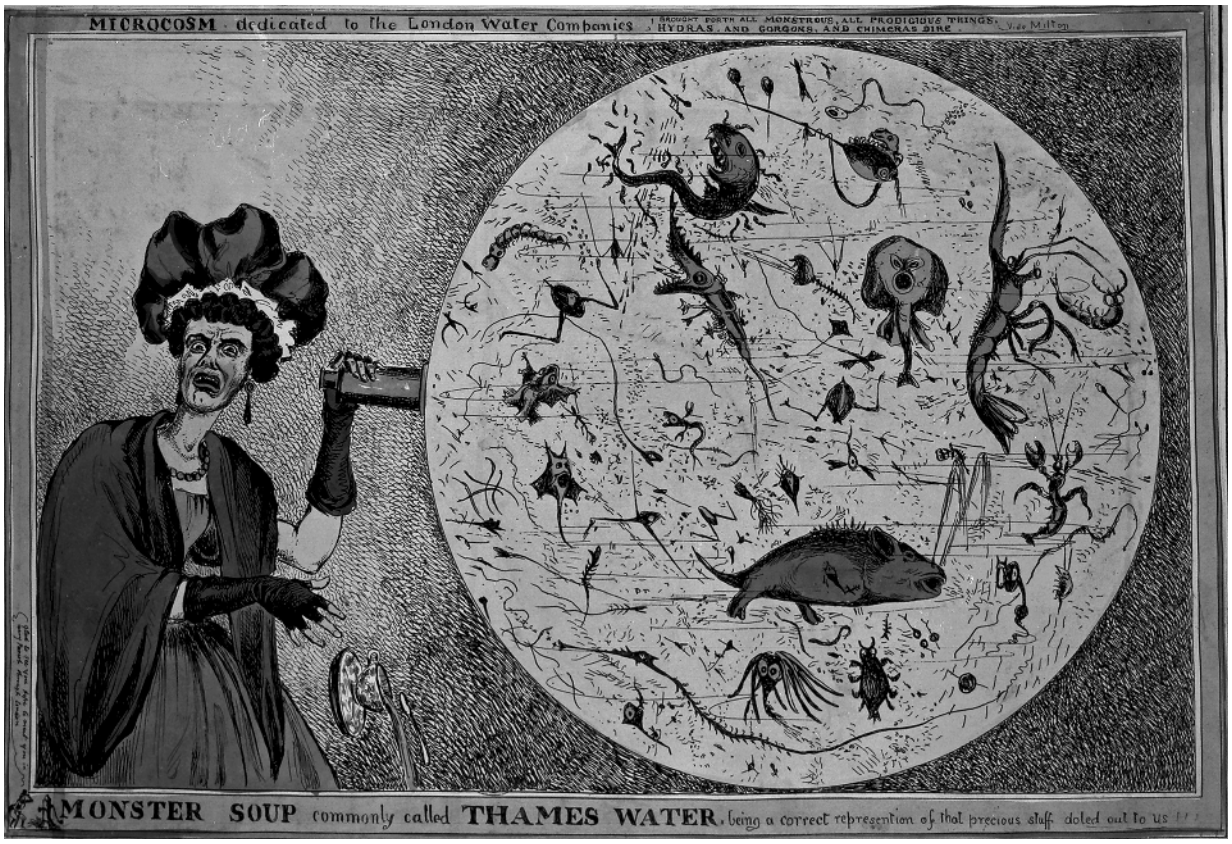

Figure 1.7 A Victorian satire: *Microcosm dedicated to the London Water Companies 'Monster soup commonly called Thames Water'* by George Cruikshank (1792–1878). (Courtesy of British Museum, London, UK/Bridgeman Images.)

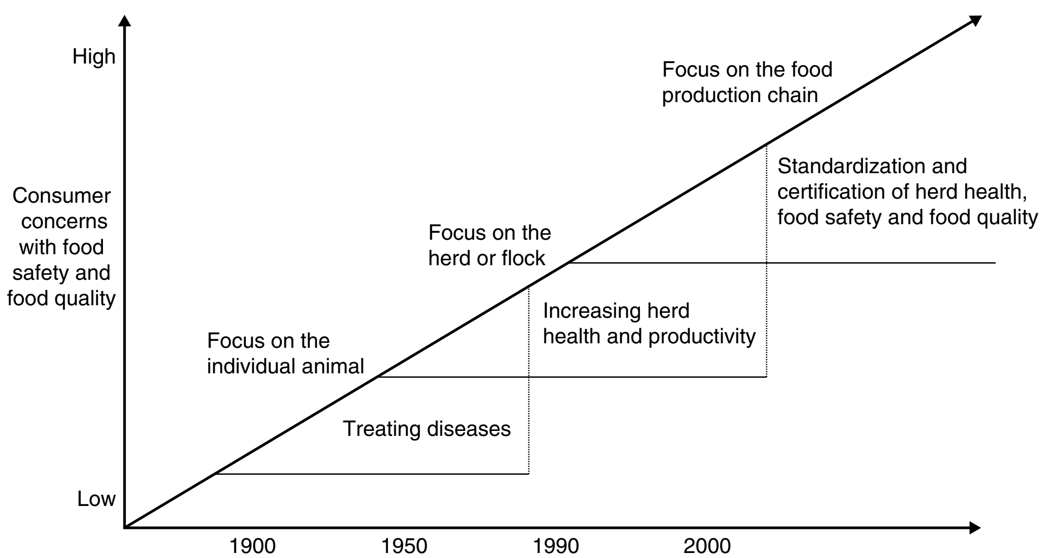

Figure 1.8 The changing focus of veterinary medicine practised in livestock, in relation to consumer concerns with food quality. (Source: *Preventive Veterinary Medicine*, **39**, Blaha, Th., Epidemiology and quality assurance application to food safety, Copyright © (1999), with permission from Elsevier Science.)

in contemporary concern for animal welfare, both among the scientific community (Moss, 1994; Appleby and Hughes, 1997; Broom and Fraser, 2015) and the general public (Bennett, 1996), and its importance is now being appreciated globally (Mellor and Bayvel, 2014)[27]. It encompasses health and 'well-being' (Ewbank, 1986; Webster, 2001)[28]. The latter term is difficult to define[29], and is also included in the *World Health Organization's* definition of human health (Old English: *hal* = 'whole') as '*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*' (WHO, 2014). Although this definition was not designed to be a framework for formulating goals of health policy (Noack, 1987), it illustrates that health is more than just absence of disease.

Obvious aspects of animal welfare are deliberate physical abuse (non-accidental injury) and neglect; contentious topics are surgical mutilation, such as tail docking of dogs (Morton, 1992), horses (Cregier, 1990) and pigs (Day and Webster, 1998), and velvet antler removal from deer (Pollard *et al*., 1992). Companion animals are known to suffer a wide range of types of physical abuse (Munro and Thrusfield, 2001a,b,c, 2015) and sexual abuse (Munro and Thrusfield, 2001d, 2005), which are remarkably similar to those found in child abuse, and a link between abuse of animals and abuse of children is now recognized (Ascione and Arkow, 1999). Other animal-welfare issues may be more subtle; for example, the relationship between bovine mastitis and use of bovine somatotropin to increase milk production (Willeberg, 1993, 1997).

Welfare in livestock production systems is often evaluated in the context of the 'five freedoms' (Spedding, 2000):

1. freedom from hunger and thirst;
2. freedom from discomfort;
3. freedom from pain, injury and disease;
4. freedom to express normal behaviours;
5. freedom from fear and distress.

Behavioural problems may be associated with intensive husbandry systems, for example, cannibalism in laying hens (Gunnarsson *et al*., 1998); but there may be less tangible issues (Ewbank, 1986) such as behavioural deprivation in sows tethered in stalls. The move towards organic farming in some Western countries is justified, in part, by improved animal welfare (Sundrum, 2001), and the veterinarian therefore is concerned with disease, productivity and well-being, all of which can be interrelated, in all types of production system (Webster, 2011).

Ethical aspects of animal welfare also are now receiving increasing attention (Algers, 2012).

National and international disease reporting

There is a requirement for improved disease reporting systems at the national and international level to identify problems, define research and control priorities and assist in the prevention of spread of infectious agents from one country to another. Additionally, residues need to be identified and eliminated (WHO, 1993). These include contamination of meat by pesticides (Corrigan and Seneviratna, 1989) and hormones (McCaughey, 1992), as well as the more long-standing issue of antibiotic residues, with the attendant problem of antibiotic resistance (Hugoson and Wallén, 2000; Teal, 2002), which can be pronounced in the less-economically-developed countries (Ibrahim *et al*., 2009)

Global goals to liberalize international trade through the *World Trade Organization* (*WTO*) (Hoekman and Kostecki, 2011) are highlighting the requirement for comprehensive disease reporting, and governmental veterinary services are responding to this need (DEFRA, 2002c). If liberalization is achieved, it will have marked effects on world trade, including that in livestock commodities (Page *et al*., 1991). An important component of free trade therefore is assessment of the **risk** of disease and related events (e.g., carcass contamination) associated with the importation of animals and animal products (Morley, 1993a,b). Established organizations, such as the *Office International des Epizooties/World Organisation for Animal Health* (*OIE*), are modifying their goals and reporting techniques, taking account of these new requirements (Blajan and Chillaud, 1991; Thiermann, 2005; Slorach, 2013).

The advent of low-cost computing following the microelectronic revolution offers powerful means of storing, analysing and distributing data. Information can be transported rapidly using modern communications systems. These developments increase the scope

[27] Concern for the welfare of animals is not just recent, though. In 1790, for example, there was public outrage over the wastage of horses in the British Army, which was losing more animals from disease and lack of care than from enemy action. This resulted, in 1795, in the Army directing that a veterinarian should be attached to each regiment. (The first to enlist as an Officer was John Shipps in 1796.) The shortage of trained veterinarians was so acute that London's Royal Veterinary College temporarily reduced its period of training from three years to three months.

[28] Animal welfare is therefore assessed primarily biologically, and is distinct from 'animal rights', which is an ethical and philosophical issue (Singer, 2000; Sandøe *et al*., 2016).

[29] For discussions of the relationships between 'welfare', 'well-being' and 'quality of life', see Appleby and Sandøe (2002) and Nordenfelt (2006).

for efficient disease reporting and analysis of the many factors that contribute to clinical disease and suboptimal production, both of which require increased statistical acumen among veterinarians.

One Health

The term 'One Health' (also sometimes termed 'Global Health': Kappas *et al*., 2012) has come to encapsulate the recognition of the link between the health of humans and animals (domestic and wild), and the environment (Atlas and Malloy, 2014; Barrett and Bouley, 2014; Grace, 2014; Bardosh, 2016). Formal descriptions of One Health include:

> 'One Health involves recognizing the essential link between human, domestic animal and wildlife health and the threat disease poses to people, their food supplies and economies, and the biodiversity essential to maintaining the healthy environments and functioning ecosystems we all require.'
>
> (From *The Manhattan Principles*: Anon., 2004)

> 'One Health is the collaborative effort of multiple disciplines – working locally, nationally, and globally – to attain optimal health for people, animals and the environment.'
>
> (One Health Initiative Task Force, 2008)

Despite recent increases in popularity and adoption of the label 'One Health', the idea has much older origins (Woods and Bresalier, 2014; Bresalier *et al*., 2015). Rudolf Virchow (1821–1902), a German physician (Saunders, 2000; Schultz, 2008), noted the intimate link between human and animal diseases in 1856: '*Between animal and human medicine, there is no dividing line – nor should there be*' (Klauder, 1958). William Ostler (1849–1919), a Canadian physician influenced by Virchow and regarded as a 'Father of Modern Medicine' and the founder of the discipline of veterinary pathology, is credited with introducing the phrase 'One Medicine' into the English-speaking world (Dukes, 2000). Within the recent history of veterinary medicine, One Health was developed by Calvin Schwabe (1984), although he also used the term 'One Medicine'. In 1979, a One Health approach was adopted in identifying the cause of a human anthrax outbreak in Russia as being accidental release of the bacterium from a military microbiology establishment, rather than ingestion of contaminated meat or contact with contaminated carcasses (Meselson *et al*., 1994).

One Health often is associated with the study and prevention of zoonotic diseases (e.g., Okello *et al*., 2011; Yamada *et al*., 2014), but it is now recognized to have a much broader scope (*Table 1.12*). Numerous groups advocating One Health have developed, including the One Health Initiative (2006) and the One Health Global Network (2011); and the *Food and Agriculture Organization of the United Nations* (*FAO*), *OIE* and the *World Health Organization* (*WHO*) have released a tripartite 'concept note'

Table 1.12 The scope of One Health. (From One Health Initiative Task Force, 2008.)

Agro-and bio-terrorism
Animal agriculture and animal sciences
Antimicrobial resistance
Basic and translational research
Biomedical research
Clinical medicine
Combating existing and emerging diseases and zoonoses
Comparative medicine
Conservation medicine
Consumer support
Diagnosis, surveillance, control, response and recovery directed at natural or intentional threats that are chemical, toxicological or radiological in nature
Entomology
Ethics
Food safety and security
Global food and water systems
Global trade and commerce
Health communications
Health of the environment and environmental preservation
Implications of climate change
Infectious disease ecology
Integrated systems for detection
Land use and production systems and practice
Mental health
Microbiology education
Occupational health
Public awareness and public communications
Public health and public policy
Regulatory enforcement
Scientific discovery and knowledge creation
Support of biodiversity
Training
Veterinary and environment health professionals and organizations
Wildlife promotion and protection

highlighting the need for collaboration among these institutions and with other stakeholders in order to advance the implementation of One Health approaches (Anon., 2010). The 'tools' of One Health are beginning to be described (Zinsstag *et al.*, 2009, 2011, 2015) and the successes of several interventions have been attributed to the One Health approach; for example, Abbas and others (2011), Häsler and coworkers (2014) and Hall and others (2016) describe a One Health approach to rabies control in Tamil Nadu, India, Colombo, Sri Lanka, and Bali, Indonesia, respectively, while Zinsstag and his colleagues (2005) report on combined human and animal health programmes in Chad to deliver childhood and livestock vaccines. A series of One Health case studies is presented by Cork and others (2016). There also is potential for the approach in controlling future disease incidents (e.g., Ebola virus outbreaks: Mwangi *et al.*, 2016).

However, despite growing interest in the concept, implementation of One Health initiatives is hampered by defects in current forms of health governance (Lee and Brumme, 2013) and currently remains somewhat sidelined, compared with the traditional discrete disciplines of human and veterinary medicine (Kahn *et al.*, 2007, 2008), where it is also appreciated less by the former than by the latter (Järhult, 2015). Moreover, the benefits of a One Health approach have yet to be fully evaluated (Rüegg *et al.*, 2017).

Translational medicine

'Translational medicine' ('translational research') is a recent neologism, initially emerging in human medicine (Woolf, 2008; Rubio *et al.*, 2010), which describes both the need to 'translate' basic scientific research into practical diagnostic procedures and therapies, and to ensure that new treatments actually reach the patients or populations for whom they are intended; that is, to bridge the gap between 'bench and field' (Tugwell and Knottnerus, 2015). It does not reflect new concepts: it merely packages, under a single name, the established idea that the results of medical and veterinary research are employed in active disease control, necessitating the breaking down of artificial boundaries between basic scientists and clinicians.

In human medicine, there has been an emphasis on translational medicine in the context of new chemotherapeutic agents to combat, for example, cancer (Chabner *et al.*, 1998) and cardiovascular disease (Adams *et al.*, 2009). However, it also legitimately encompasses the translation of medical research in a broad context; for instance, including epidemiological research such as that which identified obesity as a risk factor for coronary heart disease, which should then lead to the uptake of healthier diets by the human population (Lavie *et al.*, 2009).

In veterinary medicine, translational medicine has a similarly broad remit, including not only drug therapies but also management practices. For many years, for instance, the veterinary profession has applied the results of epidemiological research (e.g., the identification of poor hygiene as a risk factor for bovine mastitis: Neave *et al.*, 1969) to improve animal health.

Translational medicine also has a One Health dimension, where, for example, the benefit of translational research involving infectious diseases relevant to both humans and animals (e.g., the development of influenza diagnostic methods) can be maximized when both medical and veterinary research are integrated (Tang, 2013).

The success of translational veterinary medicine requires that the results of pertinent research should reach the veterinary practitioner during primary veterinary training, via journals, and by continuing professional development; and the following chapters in this book present many of the methods that are used in relevant epidemiological research.

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