Salmonellae in the environment

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Summary: Salmonellae are part of the bacterial flora normally found in Man and animals, although the frequency of occurrence is variable, reflecting the general level of Salmonella in food, water and the environment. They are widely disseminated into environments which have been disturbed by human activities. Wildlife may harbour the organisms but do not appear to be a major conduit by which the organisms enter the human and animal food chain. In areas associated with Man, salmonellae in wild animals and birds reflect the serovars disseminated into the environment. Seasonal changes in infection occur, and the capacity of the organisms to survive in nature varies. Water plays an important role in the spread of the organisms to Man and animals. Control of salmonellae must start with a significant decrease in the number of organisms which are discharged into the environment.

KEYWORDS: Bacteria - Birds - Environment - Feeds - Salmonella - Sewage - Water - Wildlife.

INTRODUCTION

At the end of the 19th century, the identification of water as a vehicle for the spread of typhoid in urban areas resulted in the development of controls in water management and the enhancement of hygiene which formed the basis of modern public and environmental health practices. While the effectiveness of these measures in the control of typhoid was dramatic, the overall effectiveness in the control of other salmonellosis is difficult to assess.

With its clinical complexities, salmonellosis is a major concern to human and veterinary medicine. The organisms can be found in practically all species of animals and are widely distributed in the natural environment. The activities of Man which have resulted in increasing modification of the environment and the natural ecology of animals, particularly in this century, have altered the previously existing ecological balance of the animal world.

Salmonellae are a diverse group of organisms; the differentiation of the organisms being based on biochemical and serological characteristics according to the Kauffmann-White Scheme. The taxonomy of the genus has been subjected to a number of changes over past years and debate on the nomenclature and taxonomic status of the organisms continues. In 1989, it was proposed that the genus be divided into two species, *Salmonella enterica*, with six subspecies and *Salmonella bongori*.

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Many serovars exist within the genus, with most of the serovars significant to Man and animals belonging to *S. enterica*, subspecies *enterica*. The serovar names, which historically were given species status (for example, *S. typhimurium*) are now reserved only for serovars of *S. enterica*, subspecies *enterica*. *S. typhimurium* is one of these serovars. As the major use of serovar determination is epidemiological tracking of serovars, changes in nomenclature have caused confusion, with the general use of historical terminology continuing. This historical usage is followed in this review for reasons of practicality.

By 1989, 2,252 serovars were recognised among the subspecies of *S. enterica*: 1,333 belonging to subspecies *enterica* (I), 452 to subspecies *salamae* (II), 92 to subspecies *arizonae* (IIIa), 302 to subspecies *diarizonae* (IIIb), 64 to subspecies *houtenae* (IV) and 9 to subspecies *indica* (V), and 15 serovars belonging to the new species *S. bongori*. Most serovars are infrequently recovered from Man or animals and do not have major epidemiological significance. Some serovars are host-adapted and associated with only a single host species; e.g., *S. typhi* in Man and *S. pullorum* in poultry. There is a wide distribution of serovars in humans, animals and the environment.

While much is known about the genetic factors and pathogenic mechanisms of *Escherichia coli* infections in Man and animals, surprisingly little is understood about the pathogenesis of salmonellosis. Factors which have been described as pathogenic mechanisms include toxins and plasmid mediated factors; however, the pathogenesis of Salmonella appears to involve interactions between a number of factors.

Salmonellosis covers a range of infections. The most common is the carrier state, in which the asymptomatic carriage of the organisms does not produce clinical disease in the host. This carriage state may last for only a short time, or it may continue for an extended period. It is most significant in the natural environment, as it results in a reservoir of the organisms and increases the capacity for spread. Some serovars are more common than others in causing invasive disease in humans and animals, a fact which further proves that the pathogenicity of different serovars varies. Gastro-enteritis is the major clinical manifestation of salmonellosis, with infection usually being self-limiting. Typhoid and paratyphoid are rarer but more serious infections of Man, with the serovars involved being host specific for Man.

Human infection is mainly acquired in the domestic environment. In developed countries, unhygienic practices and cross-contamination when food is handled are regarded as important factors in the spread of many infections.

Salmonellosis is a major environmental health problem (59). The true level of salmonellosis is difficult to assess accurately, even in developed countries. Statistics, however, suggest that the overall level of infection and carriage in Man and food animals has not changed significantly for decades. The recent international spread of *S. enteriditis*, associated with eggs, may indicate that changes are occurring (67). Changes have already occurred in serovar distribution in many countries. The factors associated with spread are as valid in 1991 as in the past. Morse and Duncan (59) suggest that, even with good environmental management of livestock and poultry, the level of salmonellosis could be reduced but not eliminated.

This article deals with the principle aspects which are recognised as important to the ecology and spread of Salmonella in the environment.
SEROVAR

Most infections are associated with the serovars of subspecies I (e.g. \textit{S. typhi}, \textit{S. pullorum}, \textit{S. typhimurium}). Within this subspecies, however, there is a wide range of serovars with varying involvement in the processes of infection as well as with host species specific relationships. While all salmonellae may be potentially pathogenic, it is possible to divide Salmonella serovars into three main subgroups:

- **pathogenic**: those frequently associated with infection in Man and animals;
- **rarely pathogenic**: those infrequently associated with infection but recovered from various sources, usually native or wild animals and the environment;
- **environmental**: those predominantly found in the environment but rarely in animals.

The serovars in these groups may vary regionally; however, \textit{S. typhimurium} remains consistently in the pathogenic group. Many other serovars vary in their pathogenicity in different regions, possibly due to strain variations. Even within \textit{S. typhimurium}, regional differences may be found in the distribution of phage types, together with differences in the apparent pathogenicity and the range of host species of some phage types.

WATER

As water is ingested by Man and animals, it may pass through the stomach into the intestines without stimulating digestion, thereby passing that natural host defence barrier to infection, increasing the potential for the establishment of infection.

Water management is central to the man-made environment. There is intense pressure to maintain the quality of water in the face of increasing contamination by bacteria and chemicals. While water is important in the spread of salmonellae and subject to contamination from wild animals, livestock, birds and Man at most stages in the water cycle, it is only one of the organisms of concern.

The survival of salmonellae in water is influenced by many factors. In one study, survival in water of \textit{S. enteriditis} was twice as long at 4°C than at 20°C (62). However, the level of organic chemicals in the water had a major effect on the survival of Salmonella, the survival time being shortened as the chemical oxygen demand (COD) level in the water increased.

The degree of pollution of certain streams was assessed by examining the watershed and the uses of the water (8); even streams assessed as unpolluted contained salmonellae. In one, salmonellae were recovered only 106 m from the origin of the stream, the probable source being terrestrial or aquatic wildlife. The predominating opinion is therefore that no surface water should be judged as potable.

The multiplication of salmonellae has been demonstrated in a warm, freshwater estuary (65). Similarly, in water contaminated with animal faeces, salmonellae can survive and even multiply due to the nutrient level. In clean water, however, the
survival rate is lower (75). Competing flora, including microflagellates, are another factor affecting the survival rate of the salmonellae in water. In one study, it was found that Salmonella survival decreased as the number of microflagellates increased (65) and that such increases in microflagellates were associated with warmer waters.

Earth dams used for water collection and storage for livestock use can become contaminated with salmonellae. In Western Australia, eight farm dams were monitored over a 17-month period with only 12 of 158 samples being positive for Salmonella (39), a similar level to that found in urban run-off water. Only five of the nine serovars found in the dams were epidemiologically significant; the others were more generally associated with wild animals than with human or livestock infection.

With regard to water systems, retention in a storage reservoir for at least ten days is considered to result in the elimination of 75 to 99% of excremental organisms (quoted in 18). The retention time must be increased if additional contamination from run-off water occurs. Experience in Australia, where roof-collected rainwater is often used for drinking in both rural and urban communities, has borne out this assumption. Although one report from Trinidad (47) has described water collected in this manner as a possible source of salmonellosis, it appears to occur very rarely.

The traditional faecal indicator organisms used for water testing do not necessarily indicate the presence or absence of Salmonella. A water-borne outbreak of salmonellosis in Riverside (California) occurred in the absence of traditional indicator organisms (2).

The metropolitan environment in most developing countries is a source of high environmental contamination from areas of poor housing and poor sanitary control. In Jakarta (Indonesia), river water and sediments were found to contain mixed Salmonella serovars (24). The predominant serovar was S. oranienburg, which was also the most common serovar in human infections in the city (25). Rivers in disadvantaged locations may be used as drains and sewers or for laundry, bathing and drinking water. The contamination in the rivers flows to the sea and, in many developing countries, seafood harvested near cities may be an important part of the food supply.

The contamination of seafood harvesting areas is of major concern in developed countries, although problems with Salmonella have not been as significant as some viral diseases.

In the aquatic environment, salmonellae may be more prevalent in the sediments than in the overlying water (34). Sediments may provide better entrapment and, in suitable temperature and nutrient conditions, foster multiplication. Aquatic fauna are then exposed to higher levels of salmonellae which leads to further colonisation and potential infection. This risk may increase in aquaculture systems.

As water flow within holding tanks increases, there is greater agitation and disturbance of the bottom sediments (51). As the turbulence increases, both the survival of salmonellae in the water and contamination rates for salmonellae in fish decrease. However, Salmonella persistence and survival in water is enhanced by the presence of fish, in part due to faecal shedding by the fish.

Frogs and other aquatic fauna in ponds, streams and wells may act as reservoirs. The initial source of the salmonellae in such fauna, however, is likely to be the water itself. Frogs probably play a secondary role in the spread of salmonellae and simply reflect the general environmental spread of the organisms.
Although salmonellae are injured by exposure to seawater, the organisms can survive after adaptation to the marine environment (57). Discharges affect the marine environment by altering the nutrient and salinity levels as well as the temperature. All of this influences the survival of bacteria, including Salmonella, although the effects are decreased by dilution as the discharge spreads.

Extensive monitoring of the marine environment in the Gulf of Aarhus (Denmark), into which a large volume of human and industrial wastewater is discharged, showed that the distribution of serovars was not wholly representative of the classically accepted chain of serovars spread from animal feeds to animals, into the human foods and finally appearing in sewage (28). The link could be seen with certain serovars; however, serovars found in animal feeds were not all found in animals. S. paratyphi B and S. typhimurium were found at similar frequencies in marine samples which did not reflect their incidence in Man.

Discharge of wastewater, particularly into water courses, is controlled by law in most countries. However, rain and natural run-off contribute significantly to the contamination of water sources in both urban and rural areas.

SEWAGE

The behaviour and survival of bacteria in sewage sludge and manures is reviewed elsewhere in this issue.

Salmonellae may grow in sewage sludge (20). This may account for the levels found in sewage even when there is a low level of salmonellosis in the supporting population.

In a study in Sweden (12), S. paratyphi B was found to be a common isolate in sewage but could not be attributed to a human or animal source. Similar findings occurred in an extensive study in Australia (79); although S. paratyphi B was found in one system fed by a large urban population, it was not found in other similar systems. This serovar has been found to multiply in sewage at 10°C and appears to survive and multiply within the sewage system (12). While S. paratyphi B in Denmark was found in waters with the same frequency as S. typhimurium, it had a lower incidence in Man (28). In the Australian study, the other serovars found were representative of those in the human population.

As sewage treatment does not remove all bacteria, bacteria are present in the final sludge. Treated sewage may be discharged into soil, rivers and the sea, resulting in a further spread of bacteria into the environment; Strauch discusses this in detail further on in this issue. Salmonellae are part of this flora. Discharge into rivers is important when the water is reused at other sites. For human usage, water decontamination is normally performed in a distribution system. Such treatment may not be performed on water for animal usage.

Investigation of twenty-three outbreaks in animals and three in humans, all of which implicated environmental factors as a source (63), found the sources of contamination to be sewage effluent in ten outbreaks, septic tank effluent in eight, sewage sludge in three, seagulls in three and abattoir effluent in two. The serovars
in the outbreaks were those found from the implicated environmental source. The transmission of the infections was attributed to the contamination of the water by the discharges.

Sewage disposal is a problem of increasing importance world-wide. Such methods of final decontamination of effluent as chlorination and ultraviolet are available; however, the costs of full-scale decontamination are prohibitive when one considers that bacteriological decontamination is only part of a total pollution control programme.

Investigation of sewage sludge spread onto pastures, and the comparison of serovars in the sludge with infection in animals on the pastures, demonstrates that animals are not seriously at risk if guidelines are followed for withholding periods between spread and release of the animals (53). However, this is not always the case for all serovars. When present in sludge, *S. typhimurium* phage type 12 has been found to cause infections in animals. As serovar differences do occur and it is not possible to control the serovars discharged into the environment, the practice of spreading sludge onto pasture must not be considered as risk-free, although the risks are extremely difficult to quantitate. Environmental conditions, such as sunlight, temperature and moisture, influence survival of *Salmonella* spread onto soils and pastures.

The processing of treated sludge for use as fertiliser increases the possible spread of salmonellae (and other organisms) to agricultural and domestic environments.

Sewage discharge into the aquatic environment, resulting in contamination of aquatic fauna (particularly shellfish) and contamination of recreational waters, increases the risk of infections in Man and animals.

**BIRDS**

Birds have been extensively investigated as a source of *Salmonella* carriage and spread, with much attention given to the role of gulls in this spread.

Free-living pigeons in London were found to have a *Salmonella* carriage rate of 17% (15), but *S. typhimurium* phage type U40 was the only serovar found in these birds. This phage type was not common in humans. While the potential for spread to humans and animals via contamination of food and water exists, the evidence indicates that infection has not occurred. In sport and breeding pigeons, the level of *Salmonella* was many times higher than in wild pigeons (64).

In the foothills of the Himalayas, Mynah birds (9%) and house sparrows (3%) provided the highest recovery of salmonellae (70). Both groups of birds were common near human habitations. The main serovars found, *S. typhimurium*, *S. saintpaul* and *S. weltevreden*, were also present in goats, poultry and Man in the same region.

Wild ducks were found to have low levels of *Salmonella* (55). The ducks probably acquired the *Salmonella* from water and recycled the organisms into the water.

Among wild birds which feed at rubbish tips and abattoirs, only gulls appeared to be significant carriers; they had a higher incidence of *Salmonella* carriage than
those at sewage ponds (66). Wild birds spread the organisms as carriers rather than as a primary source. Little evidence of Salmonella was found in wild birds feeding at sewage treatment works (61).

Gulls have been extensively surveyed. Droppings and cloacal swabs from gulls at several locations showed differences in recovery (36). Gulls foraging in relatively undisturbed shore-zone and mudflat regions — their natural forage areas — had a significantly lower isolation rate than those on tipsites and other contaminated environments. The range of serovars found were those which were epidemiologically significant in Man and livestock.

Certain serovars in gull faeces and sewage sludge at the same sites were found to correlate (17). In one study, *S. takoradi* was common in both the sludge and gull faeces although rare in the region (21). It first appeared in the sludge and then, over a period of time, in the gulls; when it finally disappeared from the sludge, it also disappeared in the gulls. This suggests that gulls are only short-term carriers and that sewage is a source of contamination for the gulls.

Monitoring of the water supply from Loch Katrine (Scotland) showed that the water quality had deteriorated (4). Bacterial contamination was seasonal and most severe in the winter when large numbers of gulls nest nocturnally. The water reservoirs were close to refuse tips (approximately 5 km) and the serovars found in the gulls were similar to those in the water. When measures were taken to frighten the gulls away from the reservoirs, Salmonella contamination was effectively controlled. The gulls were therefore considered to be vectors of transmission of the Salmonella from the tipsite to the reservoir, rather than a primary source of the organisms.

Salmonellae were found in a reservoir in the Wakefield district in England, but not in incoming water (18). Gulls were a major source of contamination; when the gulls were numerous, the water quality was low. Many of the serovars isolated from the water, such as *S. agona*, *S. derby* and *S. thompson*, were those associated with poultry, pigs and cattle. The most common serovar strain, however, was *S. typhimurium* phage type U260. This serovar was also found in gull droppings but, at the time, was not associated with other animals.

The contamination of pastures by gull faeces has been implicated in the transmission of infection to cattle. Herring gulls which fed at refuse tips and on farmland were implicated in the transmission of *S. montevideo* to sheep and cattle in the north-east of England and Scotland (11). The large number of gulls on pastures could result in significant amounts of salmonellae being deposited on the pastures over a given time. Further contamination of water used for stock could also increase the infection rates in the stock.

Herring gulls are common in Britain. Their numbers have been doubling every six years and there is a strong association with the man-altered environment; the gulls feed at refuse tips and sewage treatment sites and then roost on pastures and reservoirs. The carriage rate among gulls feeding at refuse tips in the Clyde region of Scotland was 9.2% in the breeding season and 9.8% in the non-breeding season (56). *S. typhimurium* and *S. virchow* were the most common serovars in both gulls and humans. Female gulls had a high carriage rate of 22% in the non-breeding season and a low rate of 7% in the breeding season, while male gulls maintained the same rate of 10% at all times. The variations are likely to result from changes in feeding patterns for females between the two seasons. There was no evidence of the Salmonella affecting the health of the gulls.
The carriage rates in gulls show large variations (16). Carriage rates ranged from 21.1% at dumps and sewage outfalls to 2.1% at a tipsite with domestic refuse only. The number of salmonellae in the gull faeces was also found to be low (0.18-191 per g), again suggesting that the gulls were only a vector for transmission of salmonellae.

The overall evidence indicates that gulls are only a vector for the transfer of salmonellae from one site to another, mainly from abattoirs, refuse tips and sewage to other environmental sites. The evidence also shows that the carriage of salmonellae in gulls is passive and lasts only a few days (23).

**WILD ANIMALS**

The role of wild animals in the spread of salmonellosis to livestock and Man has been investigated, but remains poorly defined. The source of many serovars can be attributed to the man-made environment and there is little information on the incidence of Salmonella in wild animals which have had no contact with environments modified by Man (54).

Zoo animals often carry Salmonella and can be a source of exotic or rare serovars. However, zoos are an altered environment for animals and the serovars are generally those associated with the animal feeds (69).

In Florida (USA), raccoons collected from the wild had a carriage rate of 17% (6). The animals were increasingly influenced by the human environment and had become scavengers near the human population. The isolated serovars were also those associated with Man in the same region. In Panama, wild forest mammals with the highest carriage rates were common scavengers which thrived in the vicinity of Man (49). Such animals, however, are probably only incidental reservoirs of salmonellae. Again, the serovars were predominantly those associated with Man in the region, *S. newport* being the most common.

In a study of wild mammals, including rodents, salmonellae were found in only 8 of 364 house mice; none were found in the remaining 905 animals studied (41). Seven of the mice had *S. dublin*, acquired from an experimentally-infected cattle herd. It was therefore concluded that wild animals did not constitute a reservoir of infection, that house mice were infected from the cattle and that the mice were vectors rather than a primary source of infection.

Serovars found in rodents, shrews, cockroaches and ants in India were those associated with human infections in the same region (73). These animals, associated with residential areas, are likely to be part of the ecological cycle. The results from India are consistent with another study in Malaysia (43). *S. bareilley* was the most common serovar found in both countries.

In Panama, large toads and certain lizards are common on grounds contaminated by wastes from Man and livestock (48). Some animals were found to be at their highest population densities in ecologically disturbed sites. Forest lizards had a much lower level of salmonellae than those near habitations. Only one serovar, *S. sandiego*, was
found in more than two species, occurring in lizards, toads and a frog. Of the serovars found, most had been implicated in cases of human salmonellosis in rural Panama. Amphibians and reptiles appear to be symptomless carriers.

In Tasmania, the island state of Australia, *S. mississippi* is the second most common serovar in the human population. This serovar is found in a variety of native wild animal species in Tasmania, although it is not usually found in food animals. Water contaminated by animals is considered the probable source of spread to the human population.

In Cornwall (UK), salmonellae were found in 7.2% of badgers over a period of fourteen years; 63% of isolates were *S. agama* and 10% *S. indiana* (14). A range of other common serovars was found. The incidence of *S. agama* and *S. indiana* was not reflected in humans or other animals.

*S. enteriditis* phage type 11 was the predominant serovar found in hedgehogs in Norfolk (UK) and were involved in infection in 10 of 13 animals from which Salmonella were isolated (46). This phage type had been recovered from humans but was extremely rare in livestock. In that region, hedgehogs appear to be the host for this phage type.

Rubbish tips are a bountiful source of salmonellae in wild animals due to relatively poor control over the types of materials dumped, with microbial considerations having a less important role than chemical contaminants. Insects, rodents, birds and other fauna become carriers with the potential to spread infection. Among birds, gulls are particularly important; their mobility and habits enable them to spread the organisms to the wider environment, particularly to water.

**REPTILES**

The subspecies III serovars of Salmonella predominate in reptiles in their natural environment; while constituting a reservoir for these serovars, reptiles may be of little importance to the overall problem of salmonellosis in the man-made environment.

Reptiles in the natural environment are carriers of salmonellae (77), but disease is not reported frequently. The range of serovars is wide and the distribution of serovars and subspecies in the wild differs from that found in other animals. *S. typhimurium*, for example, was not found in wild reptiles (52) but was common in Man and livestock. In a zoo study (quoted in 9), Salmonella did not appear to spread from one reptile to another.

Reptiles as pets have been implicated as a source of Salmonella infection in humans. Pet turtles were a source of many infections, particularly in children who handled them (7). The breeding of turtles in captivity alters the ecological balance of the reptiles, as the competitive pressures on bacteria in these artificial breeding situations, in which scavenging is replaced by artificial feeding, leads to changes in serovar distribution. The eggs of commercially-bred turtles were found to be free of Salmonella inside the shell but contaminated externally with Salmonella (40), with the serovars corresponding to those in the water and the nests. Environmental contamination and feeds were implicated as sources of the Salmonella.
High isolation rates of Salmonella were obtained from reptiles in remote Western Australia where the reptiles had no significant contact with human habitations, but similar rates were also found in reptiles near human habitations in the same region (37, 38). S. typhimurium was not found in the reptiles in remote regions (38). In Panama, reptiles showed a seasonal change in the level of Salmonella carriage, with rates significantly higher in the dry season than in the wet (50).

It may be concluded that reptiles are a potential source of contamination in Man and food animals, although the degree of risk is difficult to assess. Many of the serovars involved with wild reptiles are possibly “environmental” types associated with an ecological niche and may not have a high potential to infect Man and livestock.

AGRICULTURAL ANIMALS

Agricultural animals are an important source of Salmonella contamination through the human food chain and contribute to the spread of salmonellae into the environment. Several of the environmental considerations related to salmonellae and farm livestock have been reviewed (78). Salmonellosis in animals will be influenced by the age and management of animals.

Animal handling practices can significantly affect the number of salmonellae in animals. Particularly important are the effects of altered feeding patterns and the stress associated with holding yards before marketing and slaughter (26). Contaminated soil in holding yards is a significant source of contamination; as the animals become stressed they excrete higher levels of Salmonella onto the ground. This results in higher levels of contamination of the soil and leads to increased contamination of hides and fleeces which, in turn, contributes to the level of contamination on the carcass (27).

Extended holding of cattle in feedlots has been seen to result in a decreased level of carriage (22). Salmonella recovery was high after 18 days in a feedlot, but by 80 days it had been reduced to zero, probably as a result of the adaptation of the animals to the location.

In cattle, as with other animals, the age of animals and management practices will influence the susceptibility of animals to infection. Young animals are more susceptible to infection than adult animals and losses from infection may be greater. Animals in intensive breeding facilities are at greater risk to cross-infection than range bred animals. In both young and adult animals, contaminated water and feed are the major vehicles for the spread of infection between animals.

Poultry are a significant source of Salmonella, being readily colonised from exposure to Salmonella in their environment. The environmental contamination must be controlled in order to reduce the level of colonisation in the birds. Certain serovars, such as S. enteriditis in the USA and Europe and S. II sofia in Australia, have shown the capacity to spread rapidly and become established in the poultry chain.

When contaminated meat from food animals enters the human food chain, it becomes a potential source of human infections. Pork is contaminated with Salmonella more frequently than beef (72). This is also the case in Australia, although Australian
chicken meat is more frequently contaminated than pork. Differences in the frequency of isolation of various serovars from these sources compared with those observed in human infections indicate that there are other factors which influence the serovar spread from animals to Man. Much human infection is attributed to poor hygiene, particularly in the domestic environment, with cross-contamination from raw to prepared foods being a significant factor in transmission.

DOMESTIC ANIMALS

Pets are another potential source of Salmonella infection. Various levels of Salmonella have been reported in cats and dogs (7, 71). The serovars found probably relate to feed and the degree to which the pets are free to scavenge.

SEASON, CLIMATE AND DISTRIBUTION

In a remote part of tropical Western Australia, the Salmonella isolation (carriage) rates in wild animals are high in the wet season and low in the dry season (35). The changes are more likely due to the effect of the seasons on the animals than to effects on the bacteria. In the wet season, there is greater disposition to infection as a result of climatic effects, such as increased stress. In tropical Australia, the infection rates in humans are twofold higher in the wet season than in the dry. This contrasts with the high summer and low winter infection rates in temperate regions where the rates can be explained by inadequate food handling and insufficient hygiene during the warm months.

In temperate regions of Western Australia, where the wet winter and dry summer pattern prevails, the wet winter gives plentiful natural feed. In a study of quokkas (native marsupials) (32), the wet winter was associated with low carriage rates of salmonellae, whereas the carriage rates were high in summer owing to the lack of feed. A rapid increase in the carriage rates corresponded to the cessation of rains and depletion of feed. Infections occurred early in the summer and appeared before weight loss. During the period of infection, the mean excretion rate was 3,000 salmonellae per g of faeces. However, when food and water were plentiful in the winter, the carriage rate did not fall to zero. As stress is likely to be a major influence on animals, both carriage and infection rates and the number of organisms excreted into the environment increase. The increased environmental load of salmonellae in turn increases the number of organisms which can potentially enter the infectious cycle.

*S. virchow* is a common human isolate in Northern Australia. The level of infection in a relatively small region with moderate population density in tropical Australia is sufficient to make *S. virchow* the second most common serovar in humans on the continent (3). More than 70% of cases have been observed to occur in the five-month wet season. As previously discussed, high levels of infection have been found in animals in tropical Australia during the wet season. Environmental stress may contribute to the rise; the wet season is also associated with a rise in social disturbances
and illness among the human population. A comparison of larger cities in the north-eastern region of Australia shows annual *S. virchow* infection rates ranging from 0.008 per 1,000 in the high latitude, temperate, southern region of the state to 0.403 per 1,000 in a low latitude, tropical city located approximately 1,500 km to the north and with the same retail food distribution network. *S. virchow* appeared in the region in the 1970s and incidence rates have increased from that time.

In South Africa, subspecies II serovars constitute a relatively high proportion (6.3%) of human infections, with a wide range of serovars being involved (68). Classically, subspecies II serovars are more often associated with environmental sources; this suggests that poor hygienic conditions may be a factor in the spread of these salmonellae and that environmental sources may be significant. The frequency of isolation from humans of subspecies I serovars was 58.8 per serovar but only 4.35 per subspecies II serovar. This suggests low infectivity of subspecies II organisms and sporadic contamination from environmental sources.

Iveson considers that "wild birds and the less mobile reptilian and marsupial species present in rural areas do not present a serious infectious hazard to the farm environment or livestock, unless they have been subjected to human disturbance and exposure to contaminated man-made environments, e.g. sewerage, abattoir effluents" (38). He proposed two groupings for serovars found in Western Australia (quoted in 33):

- **native serovars**: a large group typically associated with indigenous animals and habitats and of low epidemiological significance;

- **exotic**: those associated with the man-made environment, probably introduced into the region simultaneously with human settlement, and of major epidemiological importance.

Evidence suggests that these groupings are universally valid and that they are an alternative to the groupings considered earlier.

In Malaysia where Salmonella control is developing, the predominant serovar of importance to humans is *S. typhi* (44). The most common serovars show species specific distribution: *S. typhi* (humans), *S. dublin* (cattle) and *S. II sofia* (chickens). The top ten serovars from each source account for 82% of all isolations in each group. However, only two serovars occur in the top ten for both human and non-human sources, namely *S. blockley* and *S. weltevreden*. The occurrence of *S. II sofia* in chickens is of interest.

*S. II sofia* has been the most common serovar in chickens in Australia for the past ten years. Data compiled at the Australian Salmonella Reference Laboratory shows that it first appeared in chickens in Australia in 1980 and that it spread rapidly through the poultry flocks.

*S. II sofia* dominates the Salmonella isolations from chickens and accounts for up to 67% of all Salmonella isolations annually. The serovar had been extremely rare in Australia prior to its appearance in chickens. Although well-adapted to chickens, the *S. II sofia* strain appears to have a very low infectivity for Man and other animals. The *S. II sofia* strain in Australia can be differentiated from the strain of the same serovar occurring in poultry and humans in Israel (31).
Australia has very strict quarantine controls to prevent the introduction of new animal diseases. The source of *S. II sofia* in Australian poultry is unknown. Imported feed, especially fish meal, is the most probable source. This hypothesis is supported by the fact that outbreaks in other countries, such as Malaysia (42, 44), occurred almost simultaneously.

In Guam, the level of Salmonella infection in the human population had risen to an annual rate of 218 per 100,000 by 1984 (30). Approximately 50% of these cases involved infants of less than one year, with 40% of infections caused by *S. waycross*, a serovar not commonly encountered as a pathogen in other countries. The serovar could not be implicated from food animal sources. *S. waycross* was found in soils and even domestic vacuum cleaner dust, suggesting that the infection arose from environmental contamination in homes. Although their diet consisted of insects, lizards in homes were found to carry *S. waycross*; free-ranging dogs also carried salmonellae, including *S. waycross*. The dogs may be a source of infection through their faeces, with subsequent spread by insects and lizards into homes. Footware may also contribute to spreading contamination indoors from the outside environment.

A number of delicacies of environmental origin, such as frogs legs and snails, have been implicated as sources of Salmonella. Edible snails are usually obtained from marshes and swamps and may contain pathogens, including salmonellae (1). They are usually cooked very lightly before consumption and therefore constitute a risk. Countries which are major exporters of frogs legs, such as India and Indonesia, have a high general incidence of salmonellosis in addition to poorly developed sanitation controls.

*S. hvittingfoss* was the most common serovar found in wall geckos in Nigeria (29). Australian data shows this serovar is also relatively common in Man and animals in the northern tropical regions, though rarely seen in the temperate regions. It was not reported during a two-year study of environmental, human and animal serovars in Denmark (28).

Many other serovars show distinct regional distribution as well as variation in ecological distribution within Australia. Those relatively common but primarily confined to tropical regions include: *S. cairns* (waters), *S. jangwani* (human, environment), *S. kinondoni* (human, crocodile, environment), *S. mgulani* (human, cane toads), *S. poona* (human, crocodiles), *S. treforest* (waters).

Similar regional distribution of other serovars occurs, as do those different ecological niches which have been discussed above, e.g., *S. mississippi* from Tasmania and *S. II sofia* in chickens. Regional variations of serovar distribution have been noted in other countries. Other evidence suggests that some serovars may be found in climatic regions; however, the factors influencing this distribution have not been investigated and comparative data between countries is often difficult to obtain.

**SURVIVAL IN NATURE**

Numerous studies have been performed on the survival of salmonellae in the natural environment. The major difficulty in extrapolating such information is the infinite variation of the natural environment.
Salmonellae can be found in a wide range of sources and in unfavourable environmental conditions. They have been found to exist in harsh conditions on granite outcrops; moist or wet areas have a higher recovery rate, however, which suggests that moisture plays an important role in the survival of salmonellae (76). Some serovars, such as *S. paratyphi* B in sewage, appear to survive better in the environment than do others. Salmonellae were found to survive for up to 28 weeks on pasture (45). Survival depended on climatic conditions; salmonellae survived longer in shaded areas than in those exposed to the sun.

Grass grown on a plot exposed to slurry contaminated with *S. dublin* was found to be free of salmonellae for two weeks after spreading, but the organisms could be found in the soil five months later (19). Guinea-pigs which were fed grass harvested seven weeks after the contamination did not acquire Salmonella. Healthy growing pasture crops may have natural defense mechanisms to control contaminating organisms on their surfaces. Withholding periods for pastures where sewage sludge is spread are required before opening to livestock.

Many factors affect survival in nature. Reported survival rates include (59):
- 87 days in tap water
- 115 days in pond water
- 120 days in pasture soil
- 280 days in garden soil
- over 30 months on dried bovine manure
- 28 months in avian faeces.

**ANIMAL FEEDS**

Animal feeds, particularly those produced from animal by-products, are an important source of the recycling of salmonellae into animals. Fish meal has frequently been identified as a source of Salmonella; it also plays a major role in the potential spread of the organism, as it is distributed world-wide and has been implicated as the source of outbreaks (10).

Fish become contaminated during processing even at the raw handling stage (58). Gulls feeding at processing plants have been implicated as a source of Salmonella contamination of raw fish (5). Although deep sea fish are free of salmonellae, those caught near coasts may be infected from marine discharges. Sea water at processing plants is also susceptible to Salmonella contamination; when this water is used for handling and processing, risk of contamination increases. Boats washed with polluted sea water after unloading become a source of contamination of later catches.

Only the first 30-45 min of a processing run were found to be contaminated, after which time the full processing line had risen to a temperature sufficiently high to kill salmonellae (58). Reprocessing of this first run could effectively decontaminate the entire batch. After effective processing, recontamination during packaging and distribution must be prevented.
The distribution of a Salmonella-free product has not been possible with current procedures for the processing and post-processing of feed ingredients produced from animal by-products. Control of such procedures is an essential part of Salmonella control.

**FOOD PROCESSING ENVIRONMENT**

Dairy foods have been associated with outbreaks as a result of contamination within processing plants. Major outbreaks include those of *S. bredeney* (1977, Australia) and *S. ealing* (1985, England), associated with contaminated dried milk powder, and *S. typhimurium* (1985, USA), associated with contaminated pasteurised milk. Contaminated and colonised environments within the processing factories were sources of the organisms. These problems appear to be compounded by the emergence, particularly within dairy processing factories (13), of other pathogens, such as *Listeria*. These pathogens are part of the normal environmental flora and greater environmental controls are necessary to ensure failsafe processing.

**CONTROL MEASURES**

The elimination of salmonellae must generally be considered an impossibility. Where intensive control programmes have been initiated, as with *S. typhi* and *S. pullorum*, the control of individual serovars with host specific distribution has been successful.

With the current state of knowledge and the diversity of virulence factors reported for Salmonella in Man and animals, it is not currently possible to direct control measures at specific pathogenicity factors. The virulence of individual strains does not appear to be due to one factor alone, involving a number of mechanisms acting together, the interactions of which are not understood. Similarly, factors influencing the carrier state are unknown. Host factors contributing to pathogenicity include stress, the infecting dose, the method of delivery of the organisms and the immune status of the individual. Pathogenic mechanisms of the salmonellae described include a number of different toxins, including plasmid mediated toxins, and invasiveness. In some serovars, virulence for a host species has been decreased by removing plasmids, although many salmonellae involved in infections do not carry plasmids.

The number of organisms required to establish an infection is variable. In outbreaks, high numbers of organisms in a particular food have been associated with high attack rates and short incubation periods, and low numbers with lower attack rates and longer incubation periods. The method of delivery is important as it will affect the ability of the organisms to pass the natural defences of the host. As discussed earlier, water appears to be an effective vehicle. In humans, chocolate with very low levels of Salmonella (<1 per g) has been involved in outbreaks; chocolate appears to provide protection of the organism from stomach acidity.
WHO guidelines on prevention and control of salmonellosis provide a useful line of attack against the major sources of salmonellosis spread. However, the magnitude of the problem possibly exceeds the resources for overall control.

Bacteria are part of the natural environment and exist in nature to the degree that a given environmental niche will accommodate; control or elimination of one species may enable another species to take its place. The Nurmi concept of competitive exclusion by the introduction of mixed bacterial flora is a positive intervention which is used for the control of Salmonella colonisation of poultry (60).

A significant reduction in the release of salmonellae into the environment is the first major step towards reducing the environmental load of salmonellae and spread back into the human and animal food chain.

As discussed in this review, much investigatory work has been conducted on the distribution of Salmonella serovars. However, very little work has been useful in understanding the factors affecting the ecology of salmonellae.

Epidemiological techniques of differing sensitivity have been used to monitor Salmonella distribution. Serovars are determined using the Kauffmann-White Scheme, with further subtyping of specific serovars being performed by phage typing. Internationally-recognised phage typing schemes exist for S. typhi and S. typhimurium and, more recently, for S. enteriditis. Other schemes are used regionally for the epidemiological investigation of problem serovars. Newer techniques, such as plasmid profiling and restriction fragment length polymorphism (74), are useful, but in practice are limited to investigation of specific problems. They do not, however, provide information about the factors influencing the distribution of the organisms.

CONCLUSIONS

Salmonellae are widely spread throughout the biological world. The predominant feature of Salmonella spread is human influence on the natural environment, including animal management practices, waste management and effluent control, all of which contribute significantly to the spread of salmonellae.

It is not possible to restore the natural ecological balance by returning to a pristine environment. Future control will depend on the ability of Man to intervene and control an environment which he himself has disturbed.

LES SALMONELLES DANS L'ENVIRONNEMENT. – C.J. Murray.

Résumé: Les salmonelles font partie de la flore bactérienne humaine et animale ; leur fréquence est, cependant, variable et témoigne du niveau de contamination de l'eau, de l'alimentation et de l'environnement. Elles sont largement répandues dans les milieux perturbés par les activités de l'homme. Les animaux sauvages peuvent aussi héberger ces micro-organismes mais ils ne semblent pas constituer un maillon essentiel de leur pénétration dans la chaîne alimentaire de l'homme.
et des animaux. Dans les domaines liés à l'homme, les salmonelles de la faune sauvage et des oiseaux sont bien représentatives des sérovars disséminés dans l'environnement. L'incidence des salmonelloses varie avec les saisons, et la capacité de la bactérie à survivre dans la nature est également variable. L'eau joue un rôle important dans la propagation des salmonelles à l'homme et aux animaux. La prophylaxie doit débuter par une réduction significative du nombre de germes disséminés dans l'environnement.


LAS SALMONELAS EN EL MEDIO AMBIENTE. – C.J. Murray.

Resumen: Las salmonelas forman parte de la flora bacteriana humana y animal, con una frecuencia variable que refleja el nivel general de contaminación en la alimentación, el agua y el medio ambiente. Su presencia es muy difundida en los medios perturbados por las actividades del hombre. Los animales salvajes también pueden albergar a estos microorganismos, pero no parecen constituir un conducto de primer importancia para su penetración en la cadena alimentaria del hombre y de los animales. En las zonas modificadas por el hombre, las salmonelas de la fauna salvaje y de los pájaros son representativas de los serovares diseminados en el medio ambiente. La incidencia de las salmonelas varía según las estaciones, y la capacidad de la bacteria para sobrevivir en la naturaleza también es variable. El agua tiene una función importante en la propagación de las salmonelas al hombre y a los animales. El control debe comenzar por una reducción significativa del número de gérmenes diseminados en el medio ambiente.


REFERENCES


