Pet Dogs

Daddy: Maisy has just been given a gorgeous little puppy for her birthday. Can we have one?

Photo by Stephen Andrews: https://www.pexels.com/photo/toddler-and-dog-standing-by-the-wooden-fence-9812589/

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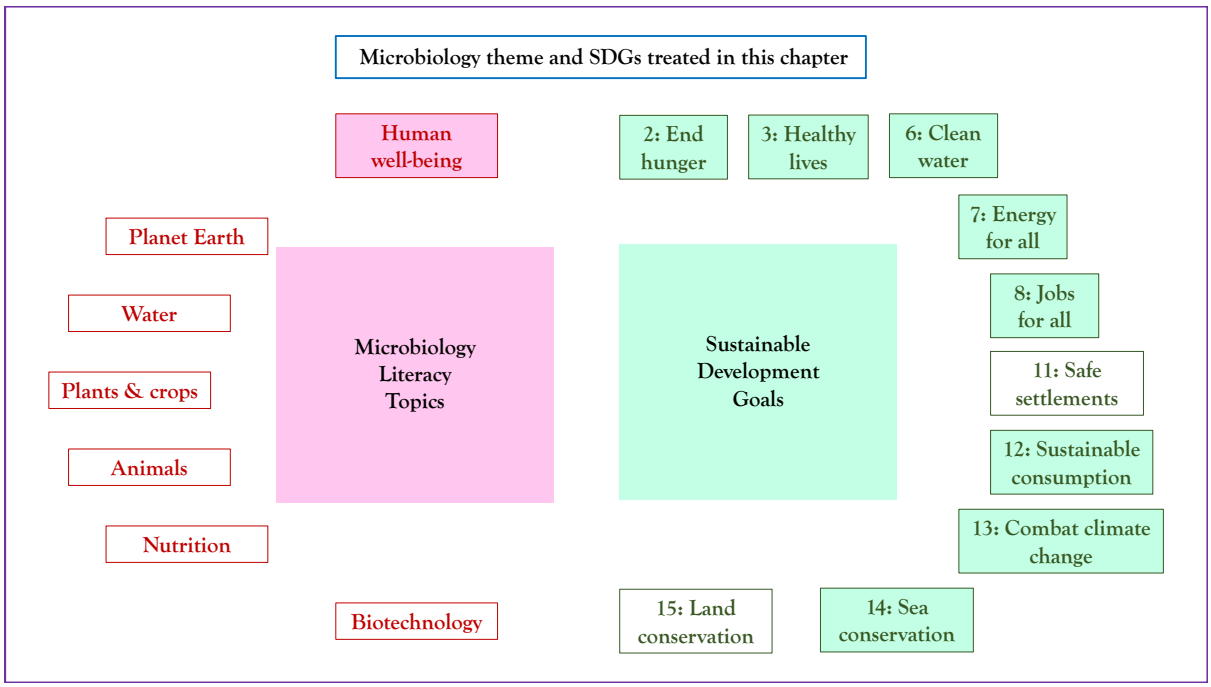
Storyline

Ownership of a pet dog is often viewed as almost a fundamental right of children and comes with significant benefits. Companion dogs provide young children with important health and developmental benefits that include **microbiome** enrichment, considered to be important for healthy immune system development and minimization of allergies, regular exercise, and development of a sense of responsibility/duty-of-care for others. The companionship/friendship/devotion dogs provide can also promote the development of feelings of joy/love/affection in children, and provide emotional support during periods of stress and unhappiness. However, pet dogs can also transmit infections and **parasites**, and come with significant environmental and energetic **footprints**, resulting principally from the production of dog food. These footprints can, however, be mitigated by a reduction in meat consumption and increased use of plant-based meat substitutes. Acquisition of a pet dog thus has multiple consequences for **Sustainable Development Goals**.

The Microbiology and Societal Context

The microbiology: microbiome enrichment and immune system development in infants; dog infections and **zoonoses**; vaccination; pollution; **eutrophication** and toxic algal blooms; microbial **greenhouse gas** production; plant-based meat substitutes. *And, peripherally for completeness of the storyline*: non-agricultural resource attribution; the business of companion pets. *Sustainability issues:* health; food and energy, economy and employment; environmental pollution; global warming.



[1] Though not the focus of this topic, and characterized by similar microbiological issues, working dogs obviously have significant additional benefits to individuals and society

Pet Dogs: the Microbiology

1. ***Pet dogs mediate exposure to a wide diversity of microbes, which is important for development of a healthy immune system.*** Domestic culture is often governed by an assumption that healthy living requires maintenance of a super-clean home. Microbes may be considered dangerous and thus to be eliminated from the home: the phenomenon of **germaphobia**, a belief encouraged by marketing strategies for some cleaning products. The COVID-19 pandemic, and official guidance to reduce virus transmission that includes the disinfection of surfaces and hands, while perfectly sensible, has amplified germaphobia. However, it is now known that an ultra-clean environment is associated with faulty immune system development in infants and subsequent susceptibility to asthma, allergies and related ailments. Exposure to a wide diversity of microbes during early childhood is thought to be crucial for healthy education-orchestration of the developing immune system.

Because of their habits and behaviour, pet dogs are excellent vehicles for the transport of outdoor microbes into the home, and within the home among its human residents, thus increasing the diversity and number of microbes to which children are exposed. In general, a companion dog will minimize development of a faulty immune system and allergies, and hence be good for the health of a child. This will in turn benefit the family, and the ensuing reduced healthcare burden and increased productivity of the resulting adult will be economically beneficial for society.

Photo by Gustavo Fring from Pexels

2. ***Dogs can catch a number of different infections, some of which they can transmit to humans.*** Infections that can be transmitted from animals to humans are called zoonoses. The best-known dog zoonosis is **rabies**, but pet dog vaccination and highly successful field vaccination campaigns to reduce rabies infections in **primary hosts**, like foxes, have reduced infections in dogs, and hence disease transmission to humans, to extremely low levels in most countries.

However, depending on the environments in which dogs are kept (urban, rural), they can acquire a number of other prevalent infections, such as **salmonellosis**, and parasites, like **ringworm** and fleas, and transmit these to family members. Because sources of infection are often other animals, disease control is based on the **One Health** approach, the integration of human, veterinary and plant health, food safety, environmental engineering, etc.

3. ***Dogs have to be vaccinated against infections.*** Like humans, dogs are routinely vaccinated against serious infections, like rabies, **canine distemper**, **canine parvovirus** (all caused

by viruses), **Lyme disease** (caused by a bacterium), and **kennel cough** (caused by a bacterium and/or viruses). The vaccines are all based on live or dead microbes, or their components, and represent an important branch of biotechnology, the commercial exploitation of biology.

As new infections emerge, and as knowledge and technological capacity grow, so new vaccines and microbially-based disease prevention products are developed. Pet ownership is thus a driver of veterinary advances and application innovation. However, vaccinations contribute significantly to the cost of having a companion pet.

4. ***Dogs can interact with livestock and wildlife, and influence conservation efforts.*** Pet dogs, particularly those living in rural settings, may engage in diverse interactions with livestock and wildlife, including hunting and **predation**, competition and habitat disturbance, pathogen transmission, and behavioural modification. As a consequence, this may create pet–livestock/wildlife conflicts that impact animal husbandry and wildlife conservation activities.

5. ***The production of dog food has a significant environmental impact and contributes to greenhouse gas emissions.*** The production of dog food involves the cultivation of crop plants (cereals, etc.) that provide plant components of dog food and, more importantly, that are used in the rearing of food animals that provide meat components of dog food (beef, chicken, fish). Other components – protein-rich residues, fats, bone meal, etc. – are obtained from by-products of the fish and meat industries.

Pet-food nutritional content and typical feeding regimes generally result in over-consumption by pets, wastage and obesity, which is counter to sustainability goals.

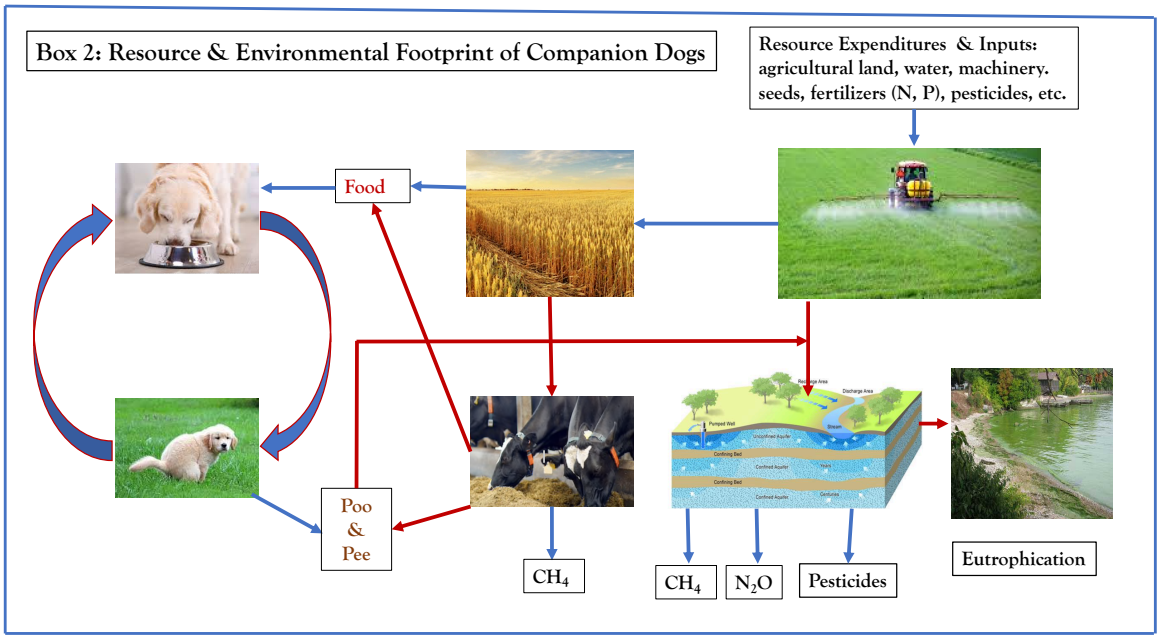
Crop plant cultivation is associated with applications of fertilizers, that primarily supply nitrogen (N) and phosphorus (P) nutrients, which are deficient and hence plant growth-limiting in most soils. However, plants only consume a fraction of applied fertilizer, and the rest **leaches** out of soils into surface waters resulting in their eutrophication: the rapid growth of large quantities – **blooms** – of **cyanobacteria** and **microalgae**, which turn the waters green.

In non-eutrophic waters, such microbes are grazed (eaten) by predators which in turn are grazed by larger predators, as part of the food chain/web. However, in eutrophic waters, some blooms may not be effectively grazed, either because the microbes produce toxins that kill the grazers, or aggregate into clumps that are too large to be eaten, so the food web is no longer functional. The blooms then die off and are degraded by other microbes that deplete the water of oxygen, thereby creating oxygen minimum zones – OMZs – which cannot support animal life. Eutrophication thus contributes to reduction of biodiversity. Worryingly, OMZs are increasing in magnitude globally in both freshwater lakes and marine systems.

Eutrophication, with its double whammy of OMZs and powerful toxins, kills off much animal life, makes such waters uninhabitable for most animals, destroys the value of toxin-affected fish and seafood, and prohibits such waters from being used for recreational purposes (you may have seen from time-to-time notices at the entrance of your favorite lake prohibiting fishing and swimming). One report suggests that the costs of damage caused by eutrophication just in the USA amounts to $ 2.2 billion per year.

Moreover, while much of the N and P enters surface water bodies, some percolates into groundwater which can be a source of drinking water, where it stimulates microbial growth. The contamination of groundwater supplies serving as sources of drinking water with **nitrates**, which are toxic and carcinogenic for humans, creates a significant health hazard. And, importantly, N reaching water bodies, groundwater and soils is metabolized by microbes, as part of the nitrogen cycle, and some of it may be converted into nitrous oxide (N_2O), a powerful greenhouse gas that contributes to global warming.

Crop cultivation also generally involves the application of large quantities of other **agrochemicals**, like **pesticides** and **herbicides**, to reduce crop losses from insect and pathogen attack. As is the case with fertilizers, much of the agrochemicals applied ends up in soil and water, and hence contributes to environmental pollution.



6. Food animals are sources of pollution and greenhouse gas emissions. Food animals themselves create faecal pollution and N-rich urine inputs into soils and waters, and hence contribute to eutrophication, pollution of surface waters and drinking water supplies. Faeces are metabolized by soil and water microbes to the greenhouse gases carbon dioxide (CO_2) and methane (CH_4), a very powerful greenhouse gas.

Moreover, cattle and sheep are ruminants – their fodder intake is digested in their **rumens** by microbes that produce substantial quantities of CH_4. In one study, it was found that, in the USA, cattle produce 26% of all methane emissions, and dog-food production represents a significant component of this. It should, however, be emphasized that increasing consumption of plant-based meat substitutes by humans and pets will enable reduction of cattle numbers, the plant fodder needed to feed them, their greenhouse gas emissions and their pollution of the environment by faeces and urine.

Box 3: Plant-based and animal cell meat substitutes

The trend to eat less meat has many causes, including religion, an unwillingness to exploit animals or tolerate their suffering, a perception that meat eating is unhealthy, a conviction that animal husbandry is inefficient utilization of resources, an unwillingness to accept the carbon footprint of food animals, especially the contribution of ruminants to methane emissions, and so forth. The problem with a vegetarian/vegan diet is that most food plants contain much less protein than food animals and, to obtain enough dietary protein, we need to supplement food-plant intake with protein-rich materials. Tofu – bean curd/coagulated soybean milk – is a traditional protein-rich supplement to vegetable diets, but there are many others, including tempeh, seitan. Microorganisms – particularly fungi -–have also been developed as meat substitutes and, currently, there is much interest in the commercial cultivation of animal cells as meat-like products not involving animal husbandry.

7. ***Dog food production involves considerable dietary energy and agricultural resource commitment***. In the USA, companion dogs and cats have been estimated to consume 19% as much **dietary energy** as is consumed by humans, and 33% as much of the animal-derived energy as is consumed by humans. Overall, dog-food production involves a significant agricultural resource commitment – personnel, energy, water, chemicals, mechanical infrastructure, etc. – including valuable agricultural land surface, which could otherwise be used for production of human food crops, biomass or energy crops, or native forests that would help soak up anthropogenic CO_2 emissions.

The total environmental impact from livestock production dedicated to pet food production – use of land, water, fossil fuels, biocides, nitrogen and phosphorous (see above) – has been calculated to amount to 30% of that needed to feed humans. Again: this will reduce as consumption of meat decreases in favour of plant-based meat substitutes.

8. ***Food-animal rearing may involve the use of growth promoters: hormones and antibiotics.*** Growth promoters used in husbandry of food animals are powerful, biologically-active substances. They and their metabolites are excreted in faeces and urine into the environment where they can affect other, non-target, animals in various ways. The use of antibiotics in agriculture and aquaculture increases both the numbers of antibiotic-resistant microbes in the environment, and the spread of resistance to **pathogens**, so contributes to the development of untreatable lethal microbial infections that previously were readily curable.

The World Health Organisation and other health agencies have designated antimicrobial resistance a medical crisis that poses a profound threat to human health in the immediate future. The risk posed by antibiotic resistance is projected to cause 10 million otherwise preventable deaths per year by 2050, at a cumulative cost of $ 100 trillion.

9. ***Dogs directly pollute the environment.*** One recent estimate suggests that, in the USA, dogs and cats produce 30% as much faecal mass as humans, almost all of which contributes to environmental pollution (i.e. is not collected and channeled to **waste water treatment plants** for processing).

Though most of the carbon is metabolized locally by microbes, as is some of its N content, and the N content of urine, some of the N leaches into surface and **groundwater reservoirs** where it causes pollution and, in surface waters, eutrophication. Some of it will be converted to the powerful greenhouse gas nitrous oxide, N_2O.

Pets also release in their faeces considerable amounts of P-containing substances into the environment (*give a dog a bone*) where it also contributes to eutrophication.

10. ***Connectivity in the biosphere.*** These pollution problems nicely illustrate the issue of connectivity in the biosphere: the chemical industry converts atmospheric N to ammonia, and the mining industry mines P, both of which are used to make fertilizer to promote crop plant growth. Some of the N and P in the fertilizer is incorporated into plant material, which is then harvested and used to produce food – in the case under discussion – for livestock and pets. These convert some of the plant N and P into animal N and P, and release some of it as waste. The livestock animals are then also used to produce pet food, and livestock N and P becomes pet N and P and pet waste, which is then is released into the environment in urine and faeces, some of which migrates to pollute surface waters and groundwater (where microbes are waiting to exploit it).

The important lesson here is: don't focus on just one link of a chain, because you'll miss the larger picture; try to see the whole chain and understand which contribution each link makes.

Relevance for Sustainable Development Goals and Grand Challenges

The microbial dimension of acquisition of a companion dog relates to several SDGs (*microbial aspects in italics*), including

- **Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture** (*end hunger and malnutrition, increase agricultural productivity).* The feeding of pet dogs sequesters land and food production resources that could otherwise be used for human food production. (Note, however, that *working* dogs – sheep dogs, etc. – make significant positive contributions to farm animal husbandry, and hence to SDG 2.). However, concerns about global warming are driving the trend towards plant-based meat substitutes, which will also reduce meat in dog food and hence agricultural resources currently committed to the production of dog food.
- **Goal 3. Ensure healthy lives and promote well-being for all at all ages** (*improve health, reduce preventable disease and premature deaths).* In addition to contributing to mental health, pet dogs mediate microbial diversity enrichment, which favours the development of a healthy immune system in infants. This in turn positively influences health by reducing allergies and asthma. (Note that *working* companion dogs - guide dogs, therapy dogs employed in care homes, etc. - confer additional, highly important positive health benefits.) They negatively influence health through transmitting disease and parasites. **Feral** and poorly managed dogs can attack humans, wild animals, livestock and domestic pets, and may represent a health risk, *inter alia* by spreading infections. Dog food production may exacerbate the challenge of antimicrobial resistance in infectious agents. All of these effects have economic consequences for health budgets.
- **Goal 6. Ensure availability and sustainable management of water and sanitation for all** (*assure safe drinking water, improve water quality, reduce pollution, protect water-related ecosystems, improve water and sanitation management).* Pet dogs contribute to deterioration of water quality through faecal pollution, including the **shedding** of pathogens, and inputs of N and P nutrients into water bodies that may cause eutrophication and, in the case of drinking water supplies, the need for additional purification measures and their associated costs. The production of dog food involves similar issues, plus inputs of pesticides and cattle growth promoters that may also enter drinking water supplies.
- **Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all** (*ensure access to clean, renewable and sustainable energy, and increase energy use efficiency).* Sustainability requires the increasing use of renewables. The use of land resources for dog food production constitutes competition for land and agricultural resources that could otherwise be used for growing biomass/bioenergy crops or maintaining native forests.
- **Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all** (*promote economic growth, productivity and innovation, enterprise and employment creation).* Companion dogs support diverse businesses based on animal pets (veterinary medicine, veterinary biotechnology, the business of dog breeding and sales, food production and sales, pre- and probiotic health products, dog accessory production and sales, etc.), and associated employment opportunities. Moreover, working dogs, such as those used for guiding the blind, herding, hunting-retrieving, guarding-protection, tracking-search-rescue, detection of substances, pulling sledges, competitive racing, etc., all contribute to diverse human employment activities.
- **Goal 12. Ensure sustainable consumption and production patterns** *(achieve sustainable production and use/consumption practices, reduce waste production/pollutant release into the*

environment, attain zero waste lifecycles, inform people about sustainable development practices). Dog wastes are not systematically recycled or rendered innocuous (though improvements could be achieved by the implementation of judicious policies). Agricultural N and P nutrients, pesticides and growth promoters used in the production of dog food mostly end up in the environment.

- **Goal 13. Take urgent action to combat climate change and its impacts** *(reduce greenhouse gas emissions, mitigate consequences of global warming, develop early warning systems for global warming consequences, improve education about greenhouse gas production and global warming).* Microbes in the rumen of cattle raised for dog food produce substantial quantities of methane. Dog and cattle faeces are degraded by microbes to CO_2. Some of the N inputs via urine from dogs, and from cattle raised for dog food, and from N fertilization during the production of fodder for dog food and cattle, are converted by microbes to N_2O. So dog ownership is associated with significant greenhouse gas production, which causes global warming-climate change. Deforestation carried out to create new agricultural land, releases already captured carbon and reduces forest carbon capture, thereby exacerbating greenhouse gas level increases.
- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development** *(reduce pollution of marine systems by toxic chemicals/agricultural nutrients/wastes like plastics, develop mitigation measures for acidification, enhance sustainable use of oceans and their resources).* N, P, pesticide and growth promoter inputs associated with dog food production, where they occur near coastal waters, may run into marine systems.

Potential Implications for Decisions

1. ***Individual***
   - **a.** Weighing up the various microbial and non-microbial factors and aligning them with personal convictions (do the personal positive health benefits outweigh the general environmental considerations?).
   - b. Large dog or small (environmental-energetic footprint will be approximately proportional to size)?
   - **c.** One dog or more (environmental-energetic footprint will be approximately proportional to number)?
   - **d.** *Non-microbial parameters: the companionship and upbringing benefits, the financial costs of purchase, feeding, vaccination and veterinary treatments, license fee, insurance, etc.)*

2. ***Community policies***
   - **a.** Local environmental consequences (pollution of public spaces and local water bodies with faeces, nitrogen, phosphorus), provision of clean drinking water,
   - **b.** Health costs associated with allergies
   - ***c.*** *Non-microbial parameters: support of local businesses - veterinary surgeries, pet shops, etc. - policy regarding dog fouling of parks, playgrounds, sports fields.*

3. ***National policies relating to dog ownership***
   - **a.** Healthcare economics of allergies and related diseases, and positive influence on mental health
   - **b.** Environmental pollution
   - **c.** Ensuring safe drinking water supplies
   - **d.** Eutrophication/algal blooms/toxic algal blooms preventing use of surface water bodies, fisheries, tourism, etc.
   - **e.** Greenhouse gas production and global warming,

f. Sequestration of agricultural land otherwise used for food and renewable production.

g. *Non-microbial parameters: policies relating to dog ownership: licensing. Same cost for multiple dogs or increasing with the number (increasing license cost is discriminatory for poorer members of society)?*

Pupil Participation

1. ***Class discussion of the issues associated with dog ownership***

2. ***Pupil stakeholder awareness***
   a. Dog ownership has positive and negative consequences for the SDGs. Which of these are most important to you personally/as a class?
   b. Can you think of anything that might be done to reduce the negative consequences, especially in the food supply chain?
   c. Can you think of anything you might personally do to reduce the environmental footprint of your dog?

3. ***Exercises***
   a. In most cities, dog waste is either ignored or handled as regular garbage. What other alternatives to disposing dog waste can you envision?
   b. Dog food is produced in large commercial facilities, often connected to food-animal processing operations. What sustainable options are there for dog food? How might you formulate a sustainable dog food and produce it for your city/town/region?
   c. Looking at the SDGs, how can we change our approach to companion animals to bring them into sustainable living? What are the challenges and opportunities? Create a sustainable city plan for companion animals and their associated environmental impacts.

The Evidence Base, Further Reading and Teaching Aids

Benefits of pet dogs
https://www.youtube.com/watch?v=7rhm081lhYU

Diversity of the microbiome, immune development and health
https://www.youtube.com/watch?v=aNKQgGmlW8w

Rook GA. 2013. Regulation of the immune system by biodiversity from the natural environment: an ecosystem service essential to health. Proc Natl Acad Sci U S A 110:18360-7 https://doi.org/10.1073/pnas.1313731110.

Sharma, A., & Gilbert, J. A. (2018). Microbial exposure and human health. *Cur Op Microbiol* 44: 79-87

Azad, M. B., Konya, T., Maughan, H. et al (2013). Infant gut microbiota and the hygiene hypothesis of allergic disease: impact of household pets and siblings on microbiota composition and diversity. *Allergy Asthma Clin Immunol* **9**: https://doi.org/10.1186/1710-1492-9-15

Ownby, D. R., Johnson, C. C., & Peterson, E. L. (2002). Exposure to Dogs and Cats in the First Year of Life and Risk of Allergic Sensitization at 6 to 7 Years of Age. *JAMA*: **288**: 963–972

Song, S. J., Lauber, C., Costello, E. K. et al (2013) Cohabiting family members share microbiota with one another and with their dogs doi: 10.7554/eLife.00458

Dog infections

https://www.who.int/news-room/fact-sheets/detail/rabies; Jacob, J. and Lorber, B. (2015) Diseases transmitted by man's best friend: the dog. https://journals.asm.org/doi/10.1128/microbiolspec.IOL5-0002-2015

Vaccinations

https://www.noah.co.uk/briefingdocument/dog-vaccination/
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/769590/_281595-v6-VMD_Position_paper_on_Authorised_Vaccination_Scedules_for_Dogs.pdf

Pet dog interactions with wildlife

Twardek, W. M., Pelman, K. S., Gallagher, A. J. and Cooke, S. J. (2017) Fido, Fluffy, and wildlife conservation: The environmental consequences of domesticated animals. Environmental Reviews 25: 381-395.

Environmental impacts of dog food production

The Rumen and methane production: https://www.youtube.com/watch?v=9gr90_OwtSc
Okin, G.S. (2017) Environmental impacts of food consumption by dogs and cats. *PLOS ONE*: journal.pone.0181301
Poore, J. and Nemecek, T. (2018) Reducing food's environmental impacts through producers and consumers. Science 360: 987-992 DOI: 10.1126/science.aaq0216
Falkowski, P. G., Algeo, T., Codispoti, L., Deutsch, C., Emerson, S., Hales, B., et al. (2011). Ocean deoxygenation: past, present, and future. *EOS Trans. Am. Geophys. Union* 92, 409–410. doi: 10.1029/2011eo460001
Swanson, K. S., Carter, R. A., Yount, T. P., Aretz, Y. and Buff, P. R. (2013) Nutritional Sustainability of Pet Foods. Adv Nutrition 4: 141–150 https://doi.org/10.3945/an.112.003335
https://www.nature.com/scitable/knowledge/library/eutrophication-causes-consequences-and-controls-in-aquatic-102364466/

Alternatives to meat-based food

https://www.bbc.co.uk/news/world-47816210
https://www.healthline.com/nutrition/vegan-meat-substitutes#section2
https://www.vox.com/2019/5/28/18626859/meatless-meat-explained-vegan-impossible-burger
https://guide.michelin.com/en/article/features/are-plant-based-meat-substitutes-the-way-to-go-in-the-dining-world

Pets and antibiotic resistance

Lloyd, D. H. (2007) Reservoirs of antimicrobial resistance in pet animals, Clin Infect Dis 45: S148-S152. https://doi.org/10.1086/519254
Guardabassi, L., Schwarz, S. and Lloyd, D.H. (2004) Pet animals as reservoirs of antimicrobial-resistant bacteria. J Antimicrob Chemother 54: 321-332 https://doi.org/10.1093/jac/dkh332
O'Neill, J. (2016) The review on antimicrobial resistance: Tackling drug-resistant infections globally: Report and recommendations. https://amr-review.org/sites/default/files/160525_Final%20paper_with%20cover.pdf

Borck Høg, B., Korsgaard, H. B., Wolff Sönksen, U. et al (2017) DANMAP 2016 - use of antimicrobial agents and occurrence of antimicrobial resistance in bacteria from food animals, foods and humans in Denmark. Sørborg, Denmark https://backend.orbit.dtu.dk/ws/portalfiles/portal/140535625/DANMAP_2016_LOW_241017.pdf

Growth promoters

Masse, D. I., Cata Saady, N. M. and Gilbert, Y. (2014) Potential of biological processes to eliminate antibiotics in livestock manure: an overview. Animals 4: 146-163 https://doi.org/10.3390/ani4020146

Pet pollution

Hobbie, S. E., Finlay, J. C., Janke, B. D., et al (2017) Contrasting nitrogen and phosphorus budgets in urban watersheds and implications for managing urban water pollution. *Proc Natl Acad Sci USA* **114**: 4177-4182 https://doi.org/10.1073/pnas.1618536114

Glossary

agrochemicals: products created by the chemical and mining industries and used in large quantities in agriculture to increase crop yields. They include fertilizers that supplement essential soil nutrients, like N and P, and pesticides that kills plant pests. Pesticides include herbicides, that kill weeds, insecticides that kill plant-eating insects and insects that transmit microbial infections, fungicides that kill fungal pathogens, and nematicides that kill pathogenic nematode worms. The problem with chemical pesticides is that their killing is not generally specific for the target pests so often has collateral activity, such as insecticides affecting essential pollinators. As such, they are environmental pollutants, the seriousness of which depends on the individual toxicity and lifetime and the non-target organisms affected.

bloom: a rapid growth of microscopic algae or cyanobacteria in water, often resulting in a colored scum on the surface

canine distemper: a highly contagious, mostly aerosol transmitted, often fatal infection of dogs and other animals affecting multiple organs. It is caused by canine distemper virus, which belongs to the same family of paramyxoviruses that cause measles and mumps in humans. A highly protective vaccine is available.

canine parvovirus: a virus causing a highly contagious, often fatal gastro-intestinal infection of (mostly) puppies, mostly transmitted through contact or faeces. A highly protective vaccine is available.

chemical pesticide: a substance or mixtures of substances intended for preventing, destroying, repelling, or mitigating any pest. Some of these affect non-target organisms and some remain in the environment for considerable periods of time, and hence constitute environmental pollutants

cyanobacteria: A large group of photosynthetic bacteria. They are among the earliest known forms of life on the earth. Together with the micro-algae, they constitute the phytoplankton which produces the biomass of the base of the aquatic food chain/web, and much of the oxygen produced in the biosphere. Some produce powerful toxins.

dietary energy: the energy provided by a particular diet and released by its consumption.

eutrophication: The excessive richness of nutrients, mostly nitrogen and phosphorus, in a lake or other body of water, frequently as a result of leaching and run-off from heavily-fertilized agricultural land, which causes a dense growth of plant/microbial life.

feral: pets, like dogs and cats, that escape domestication and become wild

footprints: the environmental cost of an activity, such the quantity of greenhouse gas produced, the energy consumed, etc.

germaphobia: the unwarranted fear of germs (=microbes), the lack of understanding that only a few can harm us and that many are essential to us or highly beneficial. Often accompanied by the unhealthy desire to kill all of them with disinfectants, etc.

greenhouse gas: gas in the atmosphere which prevents heat that the sunlight brings from escaping back into space, which results in global warming

groundwater reservoir: a subsurface reservoir of water, i.e. water-saturated subsurface, the top of which is called the water table. Groundwater reservoirs are fed by water from rainwater and surface water bodies that percolates through surface soils and sediments. Many groundwater reservoirs provide our drinking water but can only do so sustainably if the reservoirs are re-charged naturally at the same rate.

herbicide: an agent that kills unwanted plants, such as weeds, that compete with crop plants for nutrients, light and space.

kennel cough: infectious bronchitis in dogs, caused by diverse viruses and bacteria, ranging in severity from mild to lethal. Many infections are caused by *Bordetella bronchiseptica* and an effective anti-bordetella vaccine is available.

leaches: a compound applied to soil that is soluble in water will dissolve in rainwater and transfer from an immobile phase to a mobile phase, which then moves along the watershed to a surface water body or into the groundwater, as long as it is not degraded or chemically transformed.

Lyme disease: also called Lyme borreliosis, because it is caused by the bacterium *Borrelia burgdorferi*, is a vector-transmitted infection spread by infected ticks, which bite the host and inject the bacteria into the wound. It is a typical zoonotic – animal-to-human – infection with ticks transmitting the bacterium from animals like deer and rodents. Symptoms include a rash spreading from the tick bite with a so-called bull's-eye appearance, flu-like symptoms and joint pain. Though the infecting bacteria are readily killed with antibiotics, if not treated promptly, post-infection symptoms of pain and fatigue can in some cases ensue, perhaps due to an auto-immune response.

micro-algae: photosynthetic, unicellular microscopic protists (Eukaryotes that are neither fungi, plants nor animals), which, together with cyanobacteria, constitute the phytoplankton which produces the biomass of the base of the aquatic food chain/web, and much of the oxygen produced in the biosphere.

microbiome: the specific group of microbes covering and interacting with a particular organism (or other environment).

nitrates: a major form of nutrient nitrogen present in fertilizers used in agriculture.

One Health: One Health approaches are based on the fact that health does not depend solely on one parameter, like a pathogen, but is influenced heavily by the environment, and that measures to prevent disease need to deal not only with patients, but also with relevant environmental players. Examples include zoonotic infections and measures to influence transmission within and from animal sources, antibiotic resistant microbes which can be spread by animals, such as birds, fishes and especially through food animals directly into the kitchen, and food safety (contamination during long and complex supply chains).

parasite: an organism that lives on and obtains its food from another. But in the context of infections, a parasite usually means an animal, like protozoa, worms or insects like ticks and fleas.

pathogen: a microbe causing and infectious disease

predation: one organism killing another organism and consuming it as food as part of the natural food chain/web. Important predators of bacteria are protozoa.

primary hosts: the natural, preferred host of a pathogen/parasite, with the implication that other, secondary, hosts may also be infected.

rabies: a mostly lethal zoonotic infection involving inflammation of the brain. Its natural hosts are wild animals, like foxes, but transmission to humans is mostly through bites by infected dogs. An effective vaccine for both humans and pet dogs and cats is available. Rabies has been eradicated in many countries through wild animal vaccination campaigns, involving vaccine-containing meat baits that are eaten by the target animals carrying rabies, such as foxes.

ringworm: a common skin rash caused by infection by one of a number of different fungi which also cause athlete's foot. It is cured with anti-fungal medication.

rumen: the first stomach of a ruminant (an animal with a rumen, like cattle, sheep, goats), in which difficult-to-degrade plant biomass is fermented anaerobically by a complex microbial community and broken down into more easily digested components that are subsequently transferred to the rest of the digestive tract. Rumen fermentation produces methane, a powerful greenhouse gas, so the use of ruminants to produce meat, milk and skins contributes significantly to global warming.

salmonellosis: an intestinal infection by *Salmonella* bacteria causing diarrhoea and fever. Transmission is mostly via contaminated food. Antibiotic therapy is usually effective.

shedding: the release into the environment of infective microbes during an infection, usually by droplets and aerosols from the airways, typically through coughs and sneezes, by faeces, or from the skin. Poor hygiene can then transfer these microbes to food and drinks, or to other people via direct contact. Susceptible hosts can become infected by shed pathogens by breathing in droplets or aerosols, eating contaminated food, touching contaminated surfaces and transferring the microbes to a portal of entry, such as the mouth or a wound, or through direct contact with an infected person.

Sustainable Development Goals: were formulated and adopted by all United Nation Member States in 2015 as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030.

toxins: compounds that poison an essential metabolic activity and thereby cause disease.

wastewater treatment plant: a facility in which a combination of various processes (e.g., physical, chemical and biological) are used to treat municipal and industrial wastewater and remove pollutants

zoonoses: infections that are transmitted from an animal to a human, as is the case with Lyme disease, rabies and salmonellosis.