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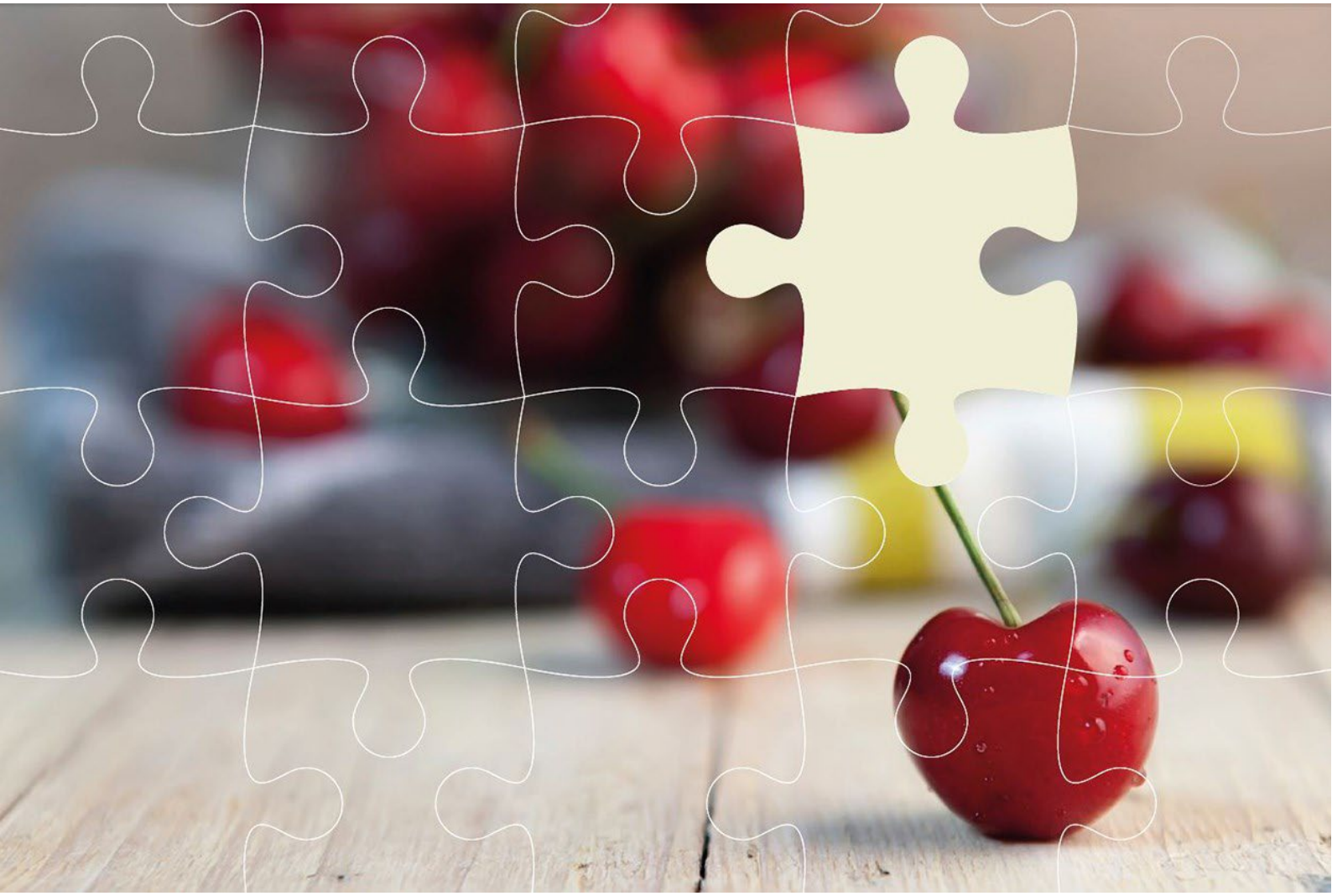

Knowledge gaps identified in VKM's scientific assessments in the fields of food and environment 2022-2024

Technical report from the Norwegian Scientific Committee for Food and Environment: The Secretariat

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Knowledge gaps identified in VKM's scientific assessments in the fields of food and environment 2022-2024

Preparation of the report

This is a report from the VKM secretariat presenting knowledge gaps identified by the scientific panels in the Norwegian Scientific Committee for Food and Environment. Selamawit Tekle coordinated the work with the report. The report covers scientific assessments published in 2022 and not included in our previous knowledge gap report (VKM 2022a), 2023, and 2024.

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Background

The Norwegian Scientific Committee for Food and Environment (VKM) periodically prepares an overview of knowledge gaps identified in VKM's scientific assessments. VKM produces risk assessments and other scientific assessments related to food safety, food production and the environment organized under thirteen scientific panels:

- Panel on animal feed
- Panel on animal health and welfare
- Panel on CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora)
- Panel on biodiversity
- Panel on biological hazards
- Panel on contaminants
- Panel on food additives, flavourings, processing aids, materials in contact with food, and cosmetics
- Panel on genetically modified organisms
- Panel on genetically modified medicinal products
- Panel on microbial ecology
- Panel on nutrition, dietetic products, novel food, and allergy
- Panel on plant health
- Panel on plant protection products

Knowledge gaps identified in medicinal products that contain or consist of GMO are not addressed in this report since the information is largely confidential and exempt from public access.

VKM's obligations to Norwegian authorities

VKM conducts independent scientific assessments for the Norwegian Food Safety Authority (*Mattilsynet*), the Norwegian Environment Agency (*Miljødirektoratet*), the Norwegian Directorate of Health (*Helsedirektoratet*), and the Norwegian Medical Products Agency (*Direktoratet for medisinske produkter*). A VKM assessment can be a risk assessment, a benefit-risk assessment, systematic review or other scientific evaluation and feedback. VKM follows international guidelines and standards for risk assessments/scientific assessments to ensure that Norwegian authorities receive independent risk assessments and other scientific assessments related to food and the environment. Risk management is not within VKM's mandate.

Introduction

Healthy and safe food is essential for good health. Since food production, dietary habits, as well as the presence of potential hazards in food are constantly changing, there is a continuous need for new knowledge to ensure healthy and safe food. Invasive alien organisms, climate change, pollution, and land use drive rapid changes in our environment, threatening ecosystems and ecosystem services. Thus, continuous monitoring and updated knowledge on existing and new threats to the environment are required.

Research and monitoring data from other countries in the fields of food and environment are important and useful but may not represent and/or are directly relevant for Norway. Knowledge relevant and directly applicable to Norwegian conditions must therefore be generated nationally. Thus, it is necessary that there are active Norwegian research communities, strong international collaborations, and relevant higher education in areas where the relevant knowledge is lacking.

Risk assessment and other scientific assessments

VKM's risk assessments typically contain three key elements: hazard identification and characterization, exposure assessment, and risk characterization. The risk characterization element integrates knowledge on hazard and exposure. The assessment is based on the scientific documentation available, including peer-reviewed articles, grey literature, previous risk assessments from national and international institutions, data from national and international surveillance and monitoring – in particular intake/exposure data, as well as studies and data provided by the industry.

The degree of confidence in the final estimation of risk depends on the variability, uncertainty and assumptions identified in all the previous steps of the assessment. Uncertainty in risk assessments is related to the variability, representativity and availability of data that the conclusion is based on. There may be incomplete knowledge of the systems, organisms, variables, or models.

Factors critical for risk assessments include:

- Accessible high quality research data and/or knowledge generated by the international scientific community or by organised surveillance or monitoring by national or international organisations with transparent and systematic methods
- Access to scientific raw and processed data from developers/industry
- Country-specific high-quality research data and other knowledge
- Access to relevant expertise within the relevant fields are essential, especially for multidisciplinary assessments
- Systematic and transparent methods for evaluating the quality and validity of data and knowledge

Data gaps refer to missing, incomplete, or poor-quality data related to the subject matter. Data gaps include everything that is uncovered as missing data during the work and not only the missing data that are associated with the basis for the conclusion. Data gaps can be associated with both variability and uncertainty. In the cases when data are absent, risks cannot be assessed.

In the VKM assessments, insufficient data uncovered during the assessment process is stated as data gaps in the reports. This report covers both data gaps and knowledge gaps, and they are referred to here under the common term 'knowledge gaps'.

This report presents knowledge gaps identified in VKM's risk assessments and other scientific assessments published in 2022 and not included in the previous research need report (VKM 2022a), in 2023, and 2024. The aim of this report is to highlight these knowledge gaps and thereby stimulate research activities to fill these needs. For knowledge gaps identified in VKM's earlier publications readers are referred to the following publications:

- Research needs of importance identified in VKM opinions within the fields of food and environment 2018-2022 (VKM, 2022a)
- Matproduksjon, mattrygghet og miljø - innspill om kunnskapsbehov til gjennomføringen av det grønne skiftet (VKM, 2022b)
- Research needs of importance for food safety and environmental protection as based on data gaps identified by VKM (VKM, 2018)
- Research needs and data gaps of importance for food safety and protection of biodiversity - From VKM's scientific opinions in the period 2005 – 2015 (VKM, 2016)
- Kunnskapshull og forskningsbehov som VKM har avdekket i sitt arbeid med risikovurderinger 2009-2010 (VKM, 2011).

The data- and knowledge gaps are presented using different formats and at varying levels of details. This is not, however, meant to reflect their relative importance. Some of the data and knowledge gaps were reformulated and/or shortened for easier accessibility and readability. Readers are encouraged to refer to the respective risk assessments for detailed context or full information regarding the presented knowledge gaps.

VKM emphasizes that this report is limited to outline knowledge gaps identified in published VKM's risk assessments and other scientific assessments. There are certainly several other knowledge gaps in the areas of food and environment that are not outlined in this report.

This report is a technical report prepared by VKM's secretariat and is not assessed and approved by the scientific committee.

1 Nutrients in food

Calculation and assessment of nutrient content

The report on **calculation and assessment of the nutrient content in a diet in line with the consultation draft for new national dietary guidelines** (VKM, Medin, et al., 2024) identified lack of concentration data for several nutrients. The following nutrients are not calculable in the dietary calculation system (Kostberegningssystem) in the food database AE22 (Department of Nutritional Sciences, University of Oslo, 2022; vitamin K, pantothenic acid, biotin, choline, fluoride, manganese, chromium, and molybdenum (VKM, Medin, et al., 2024).

2 Food additives

Emulsifiers, Stabilizers, and thickeners

VKM's **scoping review of research on gastrointestinal effects of selected emulsifiers, stabilizers, and thickeners** (ESTs) (VKM, Denison, et al., 2023) identified that there is currently not enough available data to evaluate whether ESTs may induce negative effects on the gastrointestinal tract. Well-designed studies are needed that include sufficient description of the substance tested to know that it fulfils the criteria for being used as a food additive, in addition to having a sufficient study size. Studies addressing chronic effects are needed, because it is likely that most of the population are exposed to ESTs during their entire lifetime (VKM, Denison, et al., 2023).

Plant-based and gluten-free food products

In VKM's report on mapping of **nutrients, food additives and contaminants in plant-based and gluten-free food products and their meat-, dairy- and gluten-containing counterparts** (VKM, Devold et al., 2023), data needed to fill inn data gaps were as follows:

- A more comprehensive selection of food products requires data on market shares.
- More food composition data for the new meat and dairy analogue products, as well as for the new snack products are needed.
- Comparisons of the content of nutrients, contaminants and food additives require directly comparable concentration data.

3 Food supplements

Hesperidin

VKM's **risk assessment of hesperidin** (VKM, Bodin, et al., 2024) identified the following data gaps:

- Research is needed regarding hesperidin exposure in pregnant women or breastfeeding women.
- Long term/chronic human exposure studies on hesperidin with a duration longer than 12 weeks are necessary to evaluate adverse health effects after 12 weeks of exposure (chronic exposure).
- To detect potential rare adverse effects, randomized controlled trials with larger study groups conducted to evaluate adverse effects of hesperidin intake as the primary outcome, will be required.

Quercetin dihydrate and rutin

VKM's risk **assessment of quercetin dihydrate and rutin in food supplements (**VKM, Steffensen, et al., 2024) found few publications that evaluated the adverse effects of quercetin and rutin as their main objective. Furthermore, many of the included studies were small and of short duration, even some with single dose administration. Very little data were found on the effects of quercetin and rutin on children and pregnant women, and no data on adolescents and breastfeeding women (VKM, Steffensen, et al., 2024)

Hyaluronic acid

VKM's **risk assessment of hyaluronic acid in food supplements (**VKM, Bodin, et al., 2023) uncovered the following data gaps:

- Even though hyaluronic acid is a common natural component of animal foods, still no data has been found on background exposure to natural hyaluronic acid from the diet.
- Human randomized controlled trials of effects of hyaluronic acid exceeding 12 months were not found.
- Human studies on absorption, distribution, metabolism, and excretion of hyaluronic acid are lacking.

4 Contaminants and other substances

Grilled and barbecued food

VKM's risk **assessment of grilled and barbecued food** (VKM, Mariussen, et al., 2024) identified gaps on:

- Systematic reviews on health outcomes related to consumption of grilled food in comparison with other cooking methods are lacking.
- Data on consumption of grilled food, food items, frequency of grilling and grilling method applied are missing.
- Data on occurrence of PAH and other heat-induced contaminants in food prepared by different grilling methods and by other comparable cooking methods are missing.
- Toxicological data on individual HAAs for better hazard characterization considering toxicokinetic differences between rodents and humans are missing.
- Occurrence data on HAAs in grilled food analysed with controlled and validated analytical methods are missing.

Pesticide residues in imported foodstuffs

VKM's risk assessment of **combined effects of pesticides in food** (VKM, Lyche, et al., 2022) highlighted that the Norwegian Food Safety Authority's monitoring program for pesticide residues in foodstuffs does not necessarily analyze all pesticides that may be present in the food. This applies to imported foodstuffs or food products from third countries, in particular. A more comprehensive monitoring program for pesticide residues in foodstuffs is needed to fill this gap. In addition, there is lack of information on the target organ and/or mechanism of action for some pesticide residues. Targeted research on this area is needed (VKM, Lyche, et al., 2022).

5 Cosmetic ingredients

Sunscreen

Risk-benefit assessment of sunscreen (VKM, Bruzell, et al., 2022) emphasized the following data gaps:

- Data on concentration of UV filters in sunscreens on the Norwegian market would reduce the uncertainty in the exposure estimate.
- Data on amounts of sunscreen applied in the Norwegian population would reduce the uncertainty in the exposure estimate.
- Well-designed studies on dermal absorption would reduce the uncertainty in the estimated internal exposure.
- Well-designed studies addressing health protective and adverse health effects related to sunscreen use would reduce the uncertainty in the risk and benefit characterisation.
- If validated methods for the evaluation of in vitro studies in systematic reviews had been available, the identified in vitro studies could have been included in the hazard identification and characterisation steps to support a health effect conclusion.

6 Biological hazards

Fox tapeworm

VKM's **update on assessment of risk of introduction *Echinococcus multilocularis* to mainland Norway** (VKM, Robertson, et al., 2024) uncovered a few data gaps. The size of relevant wildlife populations and their geographical distribution over time are not known precisely, although the estimates are based upon empirical observations. This applies to both rodents and foxes. It is uncertain whether this results in over or underestimation of the risks associated with *E. multilocularis*.

The risk of *E. multilocularis* entering Norway with infected untreated dogs crossing the land border (or potentially by boat) depends on the number of dogs entering Norway, the extent of treatment compliance, and the rate of infection occurrence in untreated dogs entering Norway. This, in turn, may depend upon the infection status in the countries where the dog has been prior to entry to Norway. Data for these factors are generally lacking, although there are some data on infection occurrence in some countries. Filling some of these data gaps could be achieved by implementing compliance and enforcement checks at borders, gathering data on travel patterns of arriving dogs (including those whose owners comply with *E. multilocularis* treatments). Identifying both travel and compliance patterns, as well as potential correlations between the two, might provide important data for assessing the probability of *E. multilocularis* introduction to mainland Norway with infected untreated dogs.

While most dog walks are short, some owners take their dogs on longer hikes or bike rides, often to mountain cabins or for activities like hunting and sled racing. These activities can overlap with wildlife habitats, and owners may not dispose of their dogs' faeces as they would in urban areas. Data describing the patterns and incidence of such longer trips are lacking. It is also unknown whether dog owners that engage in these activities are also more likely to travel with their dogs abroad by car and/or violate the de-worming treatment requirement prior to their return.

7 Animal health and welfare

Triploid Atlantic salmon

VKM's report on **health and welfare of triploid Atlantic salmon in aquaculture** (VKM, Rimstad, et al., 2023) identified several data and knowledge gaps. Triploid salmon have distinct needs from those of diploids and

that this can partly be mitigated by developing specific production systems for triploids. There are data gaps regarding the determination of the factors necessary for effective production of triploids. Ideally, these factors should be established through consistent findings derived from both field observations and controlled experimental studies, which would ensure a high degree of confidence in the conclusions drawn. Additionally, to minimize confounding genetic variables, it is advisable to use sibling diploid and triploid fish in such comparative studies.

VKM has gathered available data, but there are still gaps in our understanding regarding factors such as: the impact of early environmental conditions, temperature tolerance, interactions between ploidy and genotype, susceptibility to diseases, stress responses, the use of less invasive techniques for triploid production (e.g. tetraploid-diploid mating), the influence of cell size on fish physiology and timing for transfer of triploids to sea (VKM, Rimstad, et al., 2023).

It is now widely acknowledged that triploid fish exhibit distinct dietary requirements for phosphorus and histidine, although comprehensive testing of other various dietary components is still lacking. Similarly, there has been limited research into the relative susceptibility of triploid versus diploid Atlantic salmon to viral and bacterial diseases. To provide a comprehensive comparison of infection susceptibility and disease development between triploids and diploids, both field investigations and laboratory-based challenge studies with extensive epidemiological data collection are essential (VKM, Rimstad, et al., 2023).

Very few studies have compared the susceptibility to infectious agents and diseases in triploid versus diploid Atlantic salmon. In some studies, triploids have been found to be more susceptible than diploids, however, this should be verified both in laboratory and field studies (VKM, Rimstad, et al., 2023).

Separate breeding programs with specific objectives could alleviate some of the welfare and disease problems seen in triploids, given that they are heritable. So far, there is lack of knowledge on the heritability of many traits of concern in triploids, and on the level of interactions between ploidy and genotype for the same traits to conclude on the efficiency and feasibility of such genetic selection programs. Further complexity arrives as knowledge gap about the inherent genotype variability caused by the industrial induction of triploidy (VKM, Rimstad, et al., 2023).

Wild birds

VKM's report on **effects of capture, marking and tracking on welfare of wild birds** (VKM, Eldegard, et al., 2024) identified several data and knoledge gaps. There is a growing documentation in the scientific literature on animal welfare impacts resulting from the capture, handling, sampling, and marking of wild birds, but many field studies have implemented a technique without using a control group to test for possible effects and negative effects may be unpublished for selected species. Avian responses can be heterogeneous and field techniques that work well for one group of birds can have negative effects on other birds that differ in morphology, behaviour, or ecology. Some responses may be easier to observe and record in the field than others, for example breeding success is more often recorded in studies of device effects on marine species (VKM, Eldegard, et al., 2024).

In addition to a lack of knowledge about the short- and long-term impacts, there is a substantial gap in our knowledge about the immediate effects on welfare of wild birds during capture, handling, and sampling procedures. This is largely due to the scarcity of standardized studies that comprehensively assess bird behavior during such procedures (VKM, Eldegard, et al., 2024).

Individual studies in the primary literature assessing the effect of devices on birds are less frequent compared to the number of studies using such devices without a control group. Of the 732 studies where

data were extracted, 648 were controlled studies that compared birds with devices to birds that were ringed but not tagged with a device. Controlled studies typically had small sample sizes (mean = 98.6; median = 21; range= 2 to 5171) and short study durations (mean = 2.9 years; median =1 year; range = 0.003 to 29 years). These features increase the potential for errors in inference through false positives, false negatives, inflated effect sizes and incorrect direction of effects (VKM, Eldegard, et al., 2024).

From the 732 studies included in the review, a majority were focused on some form of VHF/Radio transmitters (225 studies), followed by geolocators (165 studies) and then Satellite tags (58 studies). As is indicated by the ratio of studies to articles (190 included articles, comprising 732 studies), there was an average of 3.85 outcomes for each study. Heterogeneity between studies was high where it was quantified in the meta-analyses, which reflects either the true variability in the effect due to natural variation, true variation among species/age class responses; and methodological differences among study designs and approaches that increase risk of bias such as small sample sizes or methodological artifacts. We cannot determine how much of the heterogeneity can be attributed to each of these factors, which is why we recommend better study designs and reporting to reduce heterogeneity stemming from methodological artifacts. This option would allow the heterogeneity from biological realities to be quantified and explored to obtain a better understanding of how responses to devices differ across species and across device/attachments (VKM, Eldegard, et al., 2024).

The ability to categorise outcomes in one of the 5 domains sub-categories for each study proved difficult. Decreased comfort (D3a) and Injury (D3b) were often reported due to birds removing tags or observed feather damage or skin abrasions from tagging. Information included negative reporting such as “there was no effect of the 181 device on the bird in terms of injury”. There was heterogeneity in the way that authors of the primary literature assessed the level of effect which may have implications for future use of this model. For example, for the category Energy expenditure (D1d), authors could have compared mass differences between control and intervention groups, looked at variation in time-budgets (increased or decreased activity), levels of stress hormones or observed/perceived differences between the subjects. The different outcome measures may not be a good proxy for energy expenditure, but this needs to be investigated. Researchers in several countries are required to address the 3Rs (Replacement, Reduction, Refinement) when developing proposals and research protocols that must be approved by Ethical Committees and/or Animal Welfare Authorities, but they may not ever report findings for the 3Rs in the publications resulting from the approved work. Consequently, studies of wild birds that explicitly refer to the 3R framework remain scarce in the scientific literature (VKM, Eldegard, et al., 2024).

The following data gaps were identified in VKM’s risk assessment **release of common pheasants and grey partridges** (VKM, Rueness, Asmyhr, et al., 2022).

- Very limited or no systematically gathered information exists on the practises concerning farmed gamebirds in Norway. This pertains to all aspects of acquiring, keeping, releasing and post release treatment/management of the birds.
- Peer-reviewed, empirical studies on the impacts of released common pheasants and grey partridges, relating to antagonistic interactions and competition for space and resources with native species, are lacking.
- There are limits to the knowledge relating to game-bird welfare because of the lack of systematic and comprehensive studies outlining the needs of game-birds
- No studies of impact on biodiversity from released common pheasants and grey partridges have been carried out in Norway, or under comparable conditions elsewhere in Fennoscandia.

- Limited knowledge exists about the occurrence (distribution, prevalence) of most of the pathogens and diseases described above, both in captive gamebirds, backyard poultry and wild birds. There is also limited knowledge about the host preferences and potential impact in different host species of the different pathogens.

8 Plant health

Import of soil and other growth media

VKM's assessment of **risks to Norwegian plant health posed by import of soil and other growing media from EU** (VKM, Krokene, et al., 2024) highlighted several data gaps and uncertainties. Many species of pests have incomplete or unavailable data on their geographical distribution, biology, or association with soil and growing media. This makes it difficult to assess the risk they pose accurately. There is a high frequency of missing data regarding pest characteristics, such as their life cycle ability to associate with different types of growing media and environmental conditions that favour their proliferation. For instance, species that are only partially associated with growing media or that use soil only during certain stages of their life cycle pose difficulties for accurate risk assessment (VKM, Krokene, et al., 2024).

Monitoring pathways for soil-associated pests was highlighted as a significant data gap. While monitoring programs exist, they often fail to comprehensively capture the full range of species transported through trade. Detecting soil-borne pests is a significant challenge due to their diversity and uneven distribution in growing media. Current phytosanitary inspection techniques, which rely heavily on visual inspections and small sample sizes, are insufficient for detecting pests present in low densities or cryptic stages. This limitation underscores the need for improved detection methods (VKM, Krokene, et al., 2024).

Plants imported to Norway may originally have been propagated and grown outside Europe. These plants may have been grown for several years in a non-European country, often outside greenhouse facilities. This increases the risk that the plants and associated growing media may unintentionally bring non-native species to Norway. Various organisms may colonize sterile growing media at the start of the production cycle as the plant grows (sometimes) for several years before it is transported to Norway and planted out by a customer. The rate and degree by which different growing media are colonized by pests in different environments is largely unknown, as is the effect of different management options on reducing pest colonization (VKM, Krokene, et al., 2024).

The high volumes of live plants and associated growing media imported into Norway increase the risk of pest introduction. However, data on propagule pressure, number of pests present per unit of imported plant material, is not well documented. In addition, current phytosanitary measures focus on regulated pests. The extent of the threat from non-regulated plant pests and their potential impact on Norwegian plant health is not fully understood (VKM, Krokene, et al., 2024).

Phytophthora ramorum

VKM's **risk assessment of *Phytophthora ramorum*** (VKM, Thomsen, et al., 2023) highlighted lack of knowledge on genetic background of *P. ramorum* infestations Norway. *Phytophthora ramorum* has a complex reproductive system that involves different mating types and genetic variation within these types. Further research is needed to fully understand the distribution and prevalence of different mating types and how they impact disease management strategies.

The possible relationship between *P. ramorum* virulence and evolutionary fitness of the progeny needs further research. Local infection pressures following establishment in an area are important to monitor but this has not yet been done in Norway. Uncontrolled proliferation and dissemination can provide the pathogen an opportunity to develop multilocus genotypes with new pathogenic potential on susceptible plant hosts, as demonstrated by the outbreaks of ramorum dieback on Japanese larch in the UK. It is also important to continuously update the list of *P. ramorum* host plants as new host plants are confirmed (VKM, Thomsen, et al., 2023).

Biological Control of pests

Risk assessment of *Psychrobacter* sp. as a plant protection product (VKM, Frostegård, et al., 2024) uncovered uncertainty regarding the species affiliation of the bacteria used in the plant protection product. The close taxonomic relationship between *Psychrobacter faecalis* and *Psychrobacter pulmonis* makes it difficult or impossible to differentiate between these species based only on 16S rRNA gene sequencing. A more thorough taxonomic analysis would require complete genome sequencing or multilocus sequence analysis. Knowledge on antimicrobial resistance, as well as pathogenicity, in the genus *Psychrobacter* is largely lacking. There are ecological concerns among malacologists about the use of nematodes for biocontrol purposes and data regarding effects of nematodes on native non-target molluscs is lacking (VKM, Frostegård, et al., 2024).

9 Biodiversity

Populations of native and alien species

Knowledge on the size and area of distribution of populations of species are needed for risk assessments on biodiversity. Risk assessors also need to know whether populations are fragmented and occur at few locations, and whether populations fluctuate in size, their area of distribution and number of sub-populations. This knowledge underlies assessment of cause-effect relationships, trends in biodiversity, and environmental impacts. However, there is lack of this knowledge for many native and alien species. Species in this context include invasive species, endangered species in international trade, and parasitic and pathogenic species affecting risk-assessed species and biodiversity.

Assessing the potential impact of eight species of non-native crabs intended for use as food (VKM, Velle, et al., 2024) identified a lack of information on the number and species of crabs illegally imported into Norway. This made it difficult to assess propagule pressure, and thus the likelihood for the various species being able to establish populations in Norway. This work also disclosed a lack of knowledge about competition, predation, and other potential trophic interactions between non-native and native marine species in Norway (VKM, Velle, et al., 2024).

VKM's **assessment of the risks posed by import of two species of leeches** (VKM, Kirkendall, et al., 2024) The basic ecology for leeches is surprisingly poorly known. Knowledge gaps include their modes and speed of dispersal in the landscape and impacts on amphibians and invertebrates. The impact of climate change on interactions between species in the Norwegian ecosystems is also hard to predict. The impact from climate change will likely vastly overshadow any effects of import, also when it comes to the biodiversity and ecosystem services associated with leeches and their prey (VKM, Kirkendall, et al., 2024).

The **assessment of risks posed by domestic cats to biodiversity and welfare** (VKM, Nilsen, et al., 2023) identified that there are very limited empirical data on the number and geographical distribution of feral cats in Norway, as well as the size of the individual colonies (VKM, Nilsen, et al., 2023). The data gaps have ramifications for the estimated number of prey individuals killed by cats annually, and therefore implications for the assessment of the negative impacts on biodiversity. Similarly, there are no data on the role of owned and feral cats on spread of pathogens to wildlife populations in Norway. There is also lack of data on the distribution and abundance of bat species in Norway (VKM, Nilsen, et al., 2023). There is a need for surveillance of cat predation in Norway. This includes prey selection in Norway, and how diet changes with changing availability of different prey species. This data gap relates both to selection at a higher taxonomic level (e.g., proportion of birds vs. mammalian prey) and at lower taxonomic level (e.g. the selection of different prey species) (VKM, Nilsen, et al., 2023). Missing information on prey selection reduces our ability to assess relative risk at the species level. Good estimates of kill rates of cats are available in Norway, but there is still a gap of data pertaining to exact numbers of prey for longer time periods. Most estimates are based on prey returned home and better data are needed on kill rates of cats under field conditions. Of particular importance is that there are no data on cat predation rates for vulnerable species in Norway based on dedicated primary research (VKM, Nilsen, et al., 2023).

There is lack of information on the occurrence of diseases in wild and domesticated populations of alien species that are not regarded as invasive. This includes the effects of the diseases and the potential for spread to other species of birds or mammals. This was uncovered for Northern Cardinal (*Cardinalis cardinalis*) (**Assessment of the risk to Norwegian biodiversity from private import and keeping of Northern cardinal** (VKM, Kirkendall, et al., 2023)). Similarly, non-native crabs were found to pose a high risk in relation to spread of pathogens to aquatic organisms in Norway, but there is still insufficient data on the pathogens that could follow the crabs and what impact these will have on native species in Norway (VKM, Velle, et al., 2024).

VKM's **assessment of risks to wildlife and animal welfare associated with Lodden, Sami traditional hunting of ducks in spring**, uncovered knowledge gap about population size and trends, and yearly adult survival and recruitment of duck populations This knowledge is imperative to determine sustainable hunting quotas (VKM, Ytrehus, et al., 2022). The number of ducks in Kautokeino varies greatly among years, and even among days within the same year, and among species. For the duck species present in Kautokeino during the spring hunt, the relative proportion of resident breeders versus the proportion that are just stopping over before moving on to breeding grounds elsewhere, is unknown. Because bird counts vary greatly with weather and ice conditions, relevant environmental conditions should be recorded in parallel with the bird counts. Long time series with individual data are needed to allow for the variance in population demography and environment. The impacts of hunting disturbance on target and non-target species in Kautokeino are mainly unknown. There are also considerable knowledge gaps and uncertainty about important demographic and population parameters for the species under consideration. These include knowledge on distribution, range, and habitat use throughout the year, data on arrival time in the spring, data on recruitment and migration, survival rates, data on hunting mortality versus natural mortality, and data on among-year variation in important life history parameters (VKM, Ytrehus, et al., 2022).

According to the **Risk assessment of *Stratiolaelaps scimitus* as a biological control agent of varroa mites in beehives** (VKM, Nielsen, et al., 2023), there is a need for new knowledge of the extent of negative effects on non-target prey species in the wild. Such information would help us to assess the risk more precisely for biodiversity. Furthermore, there is a need for knowledge of the species occurrence and distribution in Norway today and the extent and distribution of its use in greenhouses and polytunnels in Norway. If this information together with knowledge of the species climate tolerance (winter survival) under Norwegian

conditions would be available, we would be more able to precisely predict the outcome of an introduction and the prevalence of the species in different parts of Norway.

Ecological preferences of native and alien species

There are several knowledge gaps on the ecological preference of invasive species. VKM's **assessment of risk and risk-reducing measures related to the introduction and dispersal of the *Didemnum vexillum* in Norway** uncovered data gaps on the growth rate and survival of the various life stages of the species at different temperatures and salinity levels. There is also a lack of data on the maximum depth distribution for this species, and what factors that influence this distribution (VKM, Järnegren, et al., 2023). The report uncovered a need for more information on the potential spread of alien invasive species in ballast water within Norway. Also, the lack of information on the presence of this species on offshore installations, like oil riggs, contributed to higher uncertainty regarding possible introduction and spread through these vessels (VKM, Järnegren, et al., 2023).

The work on import of non-native crab species for food identified that there is also a knowledge gap regarding the extent of import, and the role that such import can play in establishment and spread of potentially invasive species of crabs imported as food (VKM, Velle, et al., 2024). Also, there is a lack of information on whether natural predators or other biological control mechanisms could limit the spread or impact of the investigates species of crabs. VKM also found that there is limited information on the specific temperature and environmental conditions required for the survival and establishment of potential invasive non-native crab species (VKM, Velle, et al., 2024), both under current and future climate scenarios

VKM's **assessment of risks posed by managed honey bees (*Apis mellifera*) to wild pollinators in Norway** uncovered knowledge gap about the floral preferences and diet flexibility of many pollinators in Norway, especially in response to competition from managed honey bees (VKM, Nielsen, et al., 2024). Little is known about competition between managed honeybees and other pollinators (besides wild bees), particularly in a Norwegian setting. Further mapping of pollinator communities in Norwegian ecosystems and studies on the foraging ecology of individual pollinator species are needed to understand their sensitivity to resource competition. Only a few studies have investigated the impact from managed honeybees on the fitness of wild pollinators, such as effects on growth, reproduction, and survival. Most studies have focused on resource overlap and changes in foraging behaviour rather than direct fitness effects. There is also a shortage of experimental studies manipulating the number and strength of beehives in different landscapes and with varying amounts of floral resources. Further, there are uncertainties regarding the effectiveness of maintaining a minimum distance from beehives to reduce risks. Future studies should investigate safe distances for different stocking densities and landscapes (VKM, Nielsen, et al., 2024).

Research on pathogen spillover from managed honeybees to wild pollinators and subsequent negative effects is also limited. Some studies have found virulence of honeybee pathogens in wild bees, and experimental exposure of bumblebees to honeybee pathogens have shown variation in virulence depending on the method of exposure. More research is needed to determine to what degree experimental results are realistic in natural settings. At least two honeybee associated viruses (DMV, BQCV) are widely shared with wild pollinators, but their impacts in wild pollinator populations is not well understood (VKM, Nielsen, et al., 2024).

Climate change and boreal forests

VKM's assessment of the **impact of climate change on boreal forest ecosystem** identified several important knowledge gaps (VKM, Kausrud, et al., 2022). These knowledge gaps are presented in three categories

related to: characteristics of ecosystem functioning, specific drivers and casual relationships, and regional and system context-dependencies. Each category is summarized below.

Characteristics of ecosystem functioning
Climate and climate-related drivers have complex effects on biodiversity, biotic interactions, and species and ecosystem functioning. The assessment identifies time-legged and asynchronous shifts within and between organism groups as critical areas of uncertainty. Additionally, there is insufficient knowledge about the factors that confer forest ecosystem resilience, resistance, and vulnerability, which limits, the ability to predict and mitigate threats by managing reduced forest vulnerability in a changing climate. This includes the role of land use and forestry in affecting resilience to climate change. Moreover, climate change, and especially changes in climate extremes, will impact ecosystem carbon stocks and dynamics. However, there remains a lack of understanding about of how climate change impacts the contributions and interactions between the primary producers such as trees and understory vegetation, consumers, including insect and vertebrate herbivores, and soil decomposers and mycorrhizal symbiont communities, all of which are critical in controlling the net ecosystem carbon uptake and emissions.

Specific drivers and causal relationships
Understanding the role of climate extremes and climate-related disturbances as drivers of ecological conditions in Norwegian forests are particularly important as they exert strong and predominantly negative impacts on the ecological condition of boreal forest systems. However, some functionally important organismal groups are underrepresented in research. Knowledge about the climate change impacts on understory vegetation, including dwarf-shrubs, bryophytes and lichens, and key decomposer and mutualist communities, and their role and functioning in impacting forest conditions under climate change. Similarly, the Impacts of climate change on functionally important insect species, especially considering their diverse roles in Norwegian forest ecosystems, and to what degree changes observed align with the ongoing global loss of insect biodiversity and biomass. Furthermore, animal- and plant diseases can have a large ecological impact but do not affect humans or economically important species. In general, fungal pathogens in plants are much more studied than bacteria (including phytoplasmas), oomycetes, nematodes, and viruses.

Knowledge gaps related to regional and system context-dependencies
There is also a lack of knowledge as to how local adaptation, or regional variation in responses, may impact species' resistance or resilience to climate change. There is also a need for more coordinated, long-term, ecosystem-based research and monitoring efforts for integrating field-based data with regional- and national-level knowledge systems (e.g. species distribution maps, soil conditions, climate forecasts, remote sensing and modelling tools) to develop realistic, and robust predictions for species beyond primary producers. Additionally, there is a general lack of empirical knowledge about forest ecosystem transition and succession on the scales and time frames relevant to current climate changes, calling for more comprehensive and ecologically informed assessment and monitoring.

10 Trade in endangered species of wild fauna and flora

In assessments on whether trade will be detrimental to the survival of endangered species listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), non-detriment findings (NDFs) are often associated with uncertainty due to a lack of information on several areas. A shortage of information on population size and trends, the area of distribution, levels of illegal trade as well as incomplete data on key aspects of the species' ecology are common knowledge gaps. These can make it

difficult to estimate whether international trade leads to demographic and genetic attrition of species or populations.

VKM's assessment of **risk to populations of pythons listed by CITES due to trade** (VKM, de Boer, et al., 2023) uncovered lack of up-to-date information about population sizes and trends. Gaps in knowledge on populations and species delimitation of pythons make it hard to estimate whether wild harvest leads to demographic and genetic attrition of species or populations. Furthermore, accurate trade data beyond the CITES Trade Database is lacking for many species, and illegal trade is hard to assess.

Assessing risk to populations of tortoises listed by CITES as a result of trade (VKM, Rueness, Flø, et al., 2024) also uncovered lack of reliable estimates of population sizes, population trends, and ecology. In addition, there was lack of knowledge regarding legal protective status, harvest levels, management in the range states and levels of illegal trade.

When assessing the **risk posed by trade to 12 species of crocodilians** imported or exported to/from Norway since 2011 (VKM, Rueness, de Boer, et al., 2024), the amount of peer reviewed literature and quantitative data was very good. For all but one species, the conclusions were made with high confidence, and all species had detailed conservation action plans available. However, for certain species, data gaps on reliable population sizes and trends in certain parts of the species' ranges were uncovered. There was also a lack of complete data on the ecology of some species, legal protective status, law enforcement, harvest levels and management in some range states. Additionally, information on the levels of illegal trade was not always available (VKM, Rueness, de Boer, et al., 2024).

VKM's **report on the global population of common minke whale** (VKM, Rueness, Nilsen, et al., 2022) highlighted the following data and knowledge gaps:

- Lack of knowledge on migratory patterns and location of breeding grounds,
- Lack of data of age and gender structure of populations,
- Lack of precise estimates of population size and trends,
- Lack of knowledge on the extent of ongoing distributional shifts
- Lack of knowledge on genetic structure of breeding populations
- Lack of data on bycatch, entanglement and other mortalities.
- Lack of knowledge of impact of pollutants on survival and fecundity.
- Lack of knowledge on the impact of climate change.
- Lack of knowledge about illegal trade

11 Microbial ecology

Antimicrobial resistance in the environment

Knowledge gaps identified during VKM's assessment of **antimicrobial resistance in the environment** (VKM, Nielsen, et al., 2022) are presented in three categories: Biological aspects, Methodological aspects, and Operational/reporting aspects

Biological aspects

- The overall diversity (type, mechanism, concentration) of resistance-driving agents in the environment (e.g. cleaning chemicals, various drugs including antimicrobial agents, etc.) is only described to a limited extent. More knowledge is needed regarding their role and co-selection of antimicrobial resistance traits.
- Combination toxicology/resistance (mixture toxicology)-based studies in the environment are not yet fully developed but are of importance given the expected simultaneous exposure to different resistance drivers in human-influenced environments. These include metals, solvents, oils, PHAs, pesticides, microplastics, biocides, and antimicrobials.
- Exposure rates are only described to a limited extent in the environment. The rate of decomposition and dynamics of resistance (bacteria, genes, and selective agents) dispersed from anthropogenic environments are not widely known, including the long-term effects of continuous discharges (e.g. through sewage).
- There is bias in the data on environmental resistance towards bacterial species that are culturable and that have clinical counterparts.

Methodological aspects

- There is a lack of an internationally standardized methodological framework for sampling, handling, and presenting data in non-clinical environments limits opportunities for comparative analyses.
- There is a lack of robust methods for distinguishing between acquired resistance, mobile resistance, and inherent resistance in novel environmental cells or isolates with limited history. Also, the methods for phenotypic resistance determination in specimens that cannot be cultured in the laboratory are not fully developed.
- Methodological challenges limit the focus to culturable anaerobes.
- The use of emerging experimental methods/technologies in combination with artificial intelligence and machine learning is yet to be fully explored. New technologies and new combinations of technologies including data management and analysis now quickly change the opportunities for cost-effective monitoring of resistance traits.

Operational/reporting aspects

- There is limited availability of systematic reviews and knowledge summaries – leading to poor contextualization of many studies.

There is limited discourse on the most pressing knowledge gaps and risk scenarios.

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