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ADVICE TO INFORM THE DEVELOPMENT OF A DRUG AND PESTICIDE POST-DEPOSIT MARINE FINFISH AQUACULTURE MONITORING PROGRAM IN SUPPORT OF THE *AQUACULTURE ACTIVITIES REGULATIONS*

Green fluorescein dye, used to track pesticide transport and dispersal, being released from an Atlantic salmon net-pen following an anti-sea lice tarp bath treatment. (courtesy of Fred Page, DFO, St. Andrews Biological Station)

Figure 1. Locations of marine finfish aquaculture licences in Canada. The sites shown include both active and inactive farms. Farms are located in British Columbia, New Brunswick, Nova Scotia, and Newfoundland and Labrador (Chang et al., 2021).

Context:

This Science Advisory Report is from the National Peer Review meeting held from March 2-6, 2020, titled, "Advice to inform the development of a drug and pesticide post-deposit marine finfish aquaculture monitoring program in support of the Aquaculture Activities Regulations." Disinfectants, antifoulants, and anaesthetics were outside the scope of this scientific review.

This science advice is to be used to inform cost-effective, risk-based post-deposit monitoring, mitigation, and remedial actions, with respect to drugs authorized for use under the Food and Drugs Act, and pesticides registered under the Pest Control Products Act. The post-deposit monitoring program developed based on this advice will inform amended regulations that will help Canada better respond to international commitments made under the North Atlantic Salmon Conservation Organization to protect wild Atlantic Salmon and on prevention of marine pollution under the London Protocol and Convention, two marine pollution prevention

treaties to which Canada is party (1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter).

Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule *as they become available.*

SUMMARY

- As is the case in most forms of farming, farmed fish are affected by diseases and parasites. Effective integrative health management relies on a suite of tools that include both authorized drugs and registered pesticides and non-chemical (physical, biological, or site management and husbandry) approaches. Annually, approximately three quarters of the active marine finfish aquaculture sites in Canada used at least one drug or pesticide (2016-2018). The drugs and pesticides used vary across the country by regulation (e.g., in British Columbia, sea lice control thresholds not related to farmed fish health are mandated through conditions of license) and management practices, as does the quantity of chemicals used and number and timing of treatments.
- Under the *Aquaculture Activities Regulations,* prior to the administration of drugs or pesticides, the owner/operator must first consider the use of alternatives to drug and pesticide treatments. This is an area of active research, resulting in a number of new and emerging technologies. Some are in the research and development stage and others have widespread, commercial use, with ongoing optimization and refinements. There remain knowledge gaps including those related to efficacy, environmental interactions, and fish welfare.
- In considering the use and application of authorized drugs and registered pesticides for health management, attending licensed veterinarians follow extensive and complex processes. This includes site-specific information on infection, fish, environment, husbandry, and input from site managers, as well as logistical and other factors. For the prescription of in-feed drugs, the veterinarian uses this information to prescribe an optimized treatment, which can include off-label use, and can result in additional active ingredients being used than noted on the label information. Similar analyses are undertaken when using pesticides; however, the pesticide application must follow label instructions, as well as additional provincial regulatory requirements.
- Under the *Aquaculture Activities Regulations*, from 2016-2018, the Canadian marine finfish aquaculture industry reported use of ten drugs authorized for use by Health Canada's Veterinary Drugs Directorate and two pesticides registered for use by the Pest Management Regulatory Agency within Health Canada, for the purpose of fish health control or management with the following active ingredients:
    - In-feed antibiotic drugs: oxytetracycline, florfenicol, erythromycin, ormetoprim with sulfadimethoxine, trimethoprim with sulfadiazine powder
    - In-feed pest control drugs: emamectin benzoate, ivermectin, praziquantel, lufenuron, selamectin
    - Bath pesticides: azamethiphos, hydrogen peroxide

Monitoring Program Considerations

- Clear environmental protection and pollution prevention objectives are critical prior to the design and implementation of a robust, risk-based monitoring program to quantify drug and pesticide residues in the marine environment following their use by the aquaculture industry. Clarity on the explicit objectives for an aquaculture post-deposit monitoring program are required, therefore the following advice is of a general nature.
- Designing a monitoring program is a multistep process that first considers the hazards (e.g., toxicity) and the environmental exposure (e.g., fate and pattern of use) of the drugs and pesticides used. This information helps to then define and evaluate what is appropriate to be measured in alignment with the program objectives (receptor group), the definition of thresholds of change, and the required level of confidence in assessing whether pre-defined levels of change have been exceeded. In evaluating the overall design, consideration of worker safety and technical feasibility are also required. Refinements of a monitoring program can occur when additional information is available.

Hazard and Environmental Exposure

- Currently, in-feed drugs used in marine finfish aquaculture enter the environment as feces, excretions, and any uneaten medicated feed. They are expected to be present primarily in sediments and secondarily in water or the water/sediment interface, and biota. Following the end of the treatment period, these drugs and their metabolites have been detected in sediments although their persistence varies (months to years) and is dependent on a variety of factors (e.g., the chemical properties of the specific drug, water temperature, sediment type, etc.).
- Pesticides, azamethiphos and hydrogen peroxide, enter the marine environment following release from tarps or well-boats. Treatment of a whole site may require sequential treatment of cages over a period of days. Based only on the chemical properties of the active ingredients, these pesticides are expected to remain in the water column following release, and will disperse, making sampling design challenging. These pesticides have been assessed to be non-persistent.

Methods to Define Thresholds for Drug and Pesticide Residues in the Environment

- Applicable regulatory thresholds can be designed in a variety of ways, including alignment with regulatory agencies, consistent with the development of benchmarks and/or environmental quality standards.
- Consistent with the Canadian Council of Ministers of the Environment (CCME) Canadian Environmental Quality Guidelines (1999; 2007), European guidelines for data-poor situations (TGD, 2018), and an overall weight of evidence approach, the development of Environmental Quality Standards (EQS) include explicit consideration of the quantity and quality of relevant studies, and the biological, environmental, and data uncertainties.
- Depending on the environmental protection goal and the receptor (water, sediment, biota), an EQS can be set for short- or long-term exposures. Water EQS can be divided into two main types: one related to maximum acute chemical exposure and one to chronic exposure. For sediment EQS, there is no short-term EQS (i.e., organisms would be constantly exposed

while living in the sediment). To account for scientific uncertainties, data quality and quantity, a correction or assessment factor is applied.

Modelling Exposure

- To predict the concentrations in water and sediment of in-feed drugs and bath pesticides, models may include various components such as discharge, transport, dispersal, and chemical fate and behaviour. Model predictions can assist in the identification of sampling locations and times, and the shape and location of zones of exposure and influence.
- There is a range of transport, dispersion and deposition models available; the choice of modelling approach taken needs to consider the purpose for the model output. Models that incorporate a few simplified components can be used to estimate concentrations in a generalized area for generalized time scales, whereas models that incorporate more detailed and/or additional components can be used for higher resolution estimates.
- Regardless of the model type, refinements with additional empirical data, and site-specific aspects may contribute to enhanced accuracy. The underlying uncertainties associated with the model inputs and parameterizations will influence the accuracy of the predictions.
- Modelling outputs should be validated with empirical data.

Sampling and Analysis

- Structured, probabilistic sampling designs (i.e., based on randomized selection of possible sample locations and times) allow for quantitative estimates of desired parameters and the associated uncertainties. Judgement-based design (i.e., based on existing knowledge of the area to be sampled) do not allow for statistical inference. Judgement-based design can be useful in determining what to sample (receptor or analytical endpoint) and in the design of a stratified random sampling program. A grid-based design is appropriate for capturing footprints, whereas randomized designs are more appropriate to infer population-level changes. Depending on the management objectives and other considerations, including uncertainties, either a probabilistic- or a judgement-based approach to sampling design may be appropriate.
- The sampling design needs to consider the required confidence level for evaluation of samples against the threshold, the limitations related to sample collection and handling, sample analysis, etc. All estimates of post-discharge concentrations are dependent on the initial concentration, which can vary. Therefore, in the design of post-deposit monitoring, sampling of the pre-discharge bath-water or medicated feed should be considered to confirm treatment concentrations and interpretation of results. To inform sampling design, consideration of the biological, physical and chemical characteristics of the benthic environment of the site is recommended.
- Regarding laboratory analysis for drug and pesticide quantification, a number of factors need to be considered and performance requirements established. These include stringent sample collection, storage and shipment, as well as pre-determined analytical parameters (e.g., analytes, matrices, and client-specified obtainable concentration levels).
- The mandatory laboratory requirement is to have the methods validated. Accreditation would be beneficial and may be necessary to demonstrate the competency of the laboratory for the method. Once monitoring thresholds are set, there will be a need to ensure analytical

methods are fit for purpose. There is currently limited capability and capacity within Canada to conduct these analyses with validated methods.

- Antimicrobial resistance (AMR) is a natural phenomenon in bacteria. Antibiotic use in farming can change the relative abundance of antibiotic resistant genes (ARGs) in the environment. Early empirical data on marine finfish aquaculture shows that benthic bacterial communities change in relation to distance from the farm, as do the relative frequency of ARGs.
- One method for conducting a large-scale environmental assessment of AMR is by measuring ARGs in benthic bacteria detected around marine finfish aquaculture sites. Sampling needs to consider other factors, including information about antibiotic use, background environmental levels, and persistence. There remain knowledge gaps over potential pathways, non-target organisms, spatial and temporal ecological interactions of bacterial communities, and the frequency of ARGs around marine finfish aquaculture sites. Should ARGs be found, secondary assays could be implemented, such as culture-based techniques to assess AMR.
- A post-deposit monitoring program will generate additional data that, along with new scientific data, including biological results, can be used to further refine the program over time. Standardized data reporting, transparent requirements and quality standards, and data management are important considerations for robustness of the program.

INTRODUCTION

In Canada, fish health management and regulatory control is the responsibility of both provincial and federal governments. Provincially licensed veterinarians work closely with finfish farms in all aspects of health management. They aide in the development of good farm biosecurity practices that assist with disease prevention. Veterinarians are responsible for the development and oversight of fish health monitoring programs and for the diagnosis and treatment of disease when necessary. Additionally, the provinces have developed fish health surveillance programs and regulatory requirements which are under the guidance of the respective Provincial Aquaculture Veterinarian. These surveillance programs are aimed at early detection and control of pathogens of concern to the aquaculture industry. Regulatory requirements also involve the accurate and timely monitoring of sea lice numbers on all marine finfish farms. Industry fish health veterinarians must follow these provincial programs in addition to their own independent fish health programs. Other support services such as diagnostic fish health laboratories, researchers, feed companies, and environmental consultants are also involved. Additionally, there are other provincial agencies involved with the regulatory control and use of pesticides, which are used under veterinary care and prescription for the control of sea lice.

In 2014, as stated in the *Aquaculture Activities Regulations* (AAR) Regulatory Impact Analysis Statement (Canada Gazette, 2014), and subsequently reiterated in the s.36 interdepartmental Memorandum of Understanding between Environment and Climate Change Canada (ECCC), Fisheries and Oceans Canada (DFO), and Health Canada (HC), DFO made a commitment to develop cost-effective, risk-based post-deposit monitoring, mitigation, and remedial actions, with respect to drugs and pesticides, for future incorporation into the AAR. The inclusion of a post-deposit monitoring program in the AAR will help Canada better respond to international commitments made under the North Atlantic Salmon Conservation Organization to protect wild Atlantic Salmon and on prevention of marine pollution under the London Protocol and

Convention, two marine pollution prevention treaties to which Canada is party (1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter).

As part of the interdepartmental Memorandum of Understanding (MOU), a Science Advice Implementation Plan (SAIP) was established to develop an ongoing interdepartmental science-based research advisory process to inform the development of a post-deposit monitoring program. The advisory process will also identify potential actions to take when monitoring indicates that drugs and pesticides used in aquaculture are causing an impact. The focus of the SAIP is on drugs authorized for use under the *Food and Drugs Act*, and pesticides registered under the *Pest Control Products Act*. In the Canadian marine finfish aquaculture context, the term “drug” generally applies to any in-feed product, including both antimicrobial agents (e.g., oxytetracycline) and anti-parasitic products (e.g., SLICE®, active ingredient emamectin benzoate). The term “pesticide” applies to a pest control product that is applied as an in-bath treatment (e.g., Salmosan®, active ingredient azamethiphos). Disinfectants, antifoulants and anaesthetics were outside the scope of this scientific review.

This advisory report summarizes the consensus advice from the March 2-6, 2020 Canadian Science Advisory Secretariat (CSAS) scientific peer-review meeting that included international and national scientific experts. Information and the current scientific knowledge base were presented and assessed in the following documents:

1. An Updated Review of Hazards Associated with the Use of Pesticides and Drugs Used in the Finfish Aquaculture Industry in Canada
2. Use of Pesticides and Drugs by the Canadian Aquaculture Industry in 2016 and 2017
3. Review of Antibiotic Resistance Genes (ARGs) in Salmon Aquaculture and Empirical Data on Spatial and Seasonal Trends in the Bay of Fundy
4. Alternative Treatments for Sea Lice in Salmonid Aquaculture
5. Review of Prescription and Administration Procedures of Drugs and Pesticides in Canada
6. Chemical Extraction Techniques for the Determination of Drugs, Pesticides and Antibiotics Used by the Aquaculture Industry
7. Discussion of Environmental Quality Standards (EQS) and their Development for the Monitoring of Impacts from the Use of Pesticides and Drugs at Marine Aquaculture Sites
8. Modelling and Predicting Ecosystem Exposure to In-Feed Pesticides and Drugs Discharged from Marine Fish Farm Operations: An Initial Perspective
9. Modelling and Predicting Ecosystem Exposure to Bath Pesticides Discharged from Marine Fish Farm Operations: An Initial Perspective
10. Sample Design Considerations for a Post-Deposit Monitoring Program for Pesticides and Drugs Discharged from Salmon Open Net-Pen Farming Operations

This information was used to address the following objectives by providing scientific advice on:

- aspects of the monitoring and measurement of drugs and pesticides residues in the environment immediately surrounding aquaculture facilities, such as how and where to sample and how to interpret residue concentrations in sediments;
- how to create applicable regulatory thresholds that embody the precautionary approach through the development of Environmental Quality Standards (EQS);

- how to model potential dispersion and deposition of drugs and pesticides; and
- how to assess antimicrobial resistance (AMR) as an impact from antibiotic deposition.

At the time of this advice process, the management objectives for a post-deposit monitoring program had not yet been developed and, as such, the above documents and the resulting science advice could not be tailored to specific monitoring goals and are therefore general in nature.

ANALYSIS

Overview of Finfish Aquaculture Health Management

As is the case in most forms of mono-culture, farmed fish are affected by diseases and parasites, which must be treated; the consequences of untreated disease and parasite infestations can result not only in the loss of product, but also serious fish welfare issues. Effective integrated pest management and health management of the marine finfish aquaculture industry relies on the use of both chemical (e.g., drugs, pesticides, antibiotics, disinfectants, etc.), and non-chemical strategies such as physical, biological, site management and husbandry approaches. Prior to the administration of drugs and pesticides, the AAR requires that industry first consider viable alternative, non-chemical measures.

In Canada, only products that are registered under the *Pest Control Products Act* and the *Food and Drugs Act* and are regulated by Pest Management Regulatory Agency and the Veterinary Drugs Directorate in Health Canada are allowed to be used to preserve the best health and welfare of fish in aquaculture facilities. These products are only used under authority and supervision of a registered veterinarian. The veterinarians consider a variety of site-specific information, including fish behaviour, environmental conditions, site records and information from monthly site visits and from an ongoing dialogue with site managers, to determine the appropriate prescription for maintaining the health of farmed fish.

In managing sea lice, naturally occurring ectoparasites that are a global challenge for the Atlantic salmon farming industry, the industry undertakes sea lice counts, in accordance to the conditions of license in the province where they are operating. Farms also institute integrated pest management practices, which can include anti-sea lice treatment options for both in-feed drug treatment and pesticides, which are administered as bath treatments, either in a tarped cage or using a well-boat. The use of pesticides must follow the application details within the registered product label. The attending veterinarian's decision to use an anti-sea lice treatment will be informed by trends in sea lice counts and site specific aspects (i.e., life stage of farmed fish, environmental conditions, prior treatments, and conditions of license).

Both the application and efficacy of treatments may be impacted or altered by environmental conditions (e.g., dissolved oxygen levels, presence/absence of algal blooms), mechanical issues, calculation errors due to uncertainties related to the numbers and size range of fish to be treated or the volume to be treated, time required to manufacture and ship medicated feeds, access to infrastructure (i.e., well-boats), and a large variety of other factors. Additionally, for pesticides, it can be a challenge to obtain and maintain the target treatment concentration during tarp applications, but in some situations tarp application may be the only option available.

As veterinarians consider the health of stocked fish, they may consider using both chemical and non-chemical measures to treat infections, diseases and parasites. For example, to manage sea lice, there have been a number of advances in non-chemical management and treatment

options. Some of these alternative approaches are still under development while others are in commercial and widespread use by farms. These include vaccines, cleaner fish, light traps and alternate husbandry strategies. As research advances and experience with the use of these various alternative treatments increases, refinements and optimization to both non-chemical and chemical treatments and management of sea lice on farms are occurring. There remain many unknowns surrounding the efficacies of these strategies and technologies, and more information will be needed to characterize the environmental interactions that may come with the use of each of these treatments.

DFO, provincial regulators, and the industry themselves all have policies in place requiring the implementation of appropriate fish health management strategies and tools. In British Columbia, DFO is the principal regulator of aquaculture (as of 2010) under the Pacific Aquaculture Regulations; however, pesticide use is also regulated by the Province. In other provinces, the marine finfish aquaculture industry is regulated by the provincial government and, as such, the quantity of chemicals used, number, and timing of treatments undertaken or administered varies across the country in response to differing regulations and management practices.

As of 2015, the AAR requires all licensed marine finfish net-pen farms in Canada to report all products that are deposited to the aquatic environment during regular operation of aquaculture facilities, including in-feed antibiotic drugs, in-feed pest control drugs and pesticides applied in tarp or well-boat treatments. The data are published as the National Aquaculture Public Reporting Data (NAPRD) on the Open Government portal (DFO, 2020). The first full year of data collection was for drug and pesticide usage undertaken during 2016. For the current review, datasets for 2016, 2017 and 2018 were considered. This period of time is insufficient to analyze for trends. This regulatory reporting is on an annual basis, rather than by production cycle.

From 2016-2018, the Canadian marine finfish aquaculture industry reported use of 12 different drugs and pesticides for the purpose of fish health control or management. These include five in-feed antibiotic drugs, five in-feed pest control drugs, and two pesticides applied as bath treatments.

Annually, from 2016-2018, there were 332 licensed commercial finfish net-pen farm sites in Canada (see Figure 1), and approximately three quarters (76%) of these licensed farm sites reported the use of one or more chemicals for disease or pest control during that time (see Figure 2). It is probable that most or all of the other 24% of sites were or became inactive during the period of interest.

The number and selection of sea lice treatments is reflective of differences in the size of the industry, the environment, and regulatory differences among provinces. The products available for use vary among provinces, and in BC, is there a regulatory requirement to conduct regular sea lice counts and reduce the number of sea lice if an average of three or more motile sea lice per farmed fish are found. Environmental factors also differ significantly among provinces, impacting when treatments are undertaken. For example, the reporting data from the three years clearly show that in BC, where climate and water temperatures are milder, treatments occurred in all months of the year, whereas in NB and NL treatments rarely occurred in the winter and early spring, and in NS the only treatments that occurred were in August 2016.

The AAR require that the frequency of treatments and quantity of drugs and pesticides used be reported. Within the submitted data there appears to be different interpretations as to what constitutes a treatment, particularly as it relates to administering pesticides to a site which may occur over multiple days. Clarifying the information requirements in treatment reporting will help

to ensure a more consistent dataset that can be reliably used to characterize the timing and locations of where drugs and pesticides have been released into the marine environment.

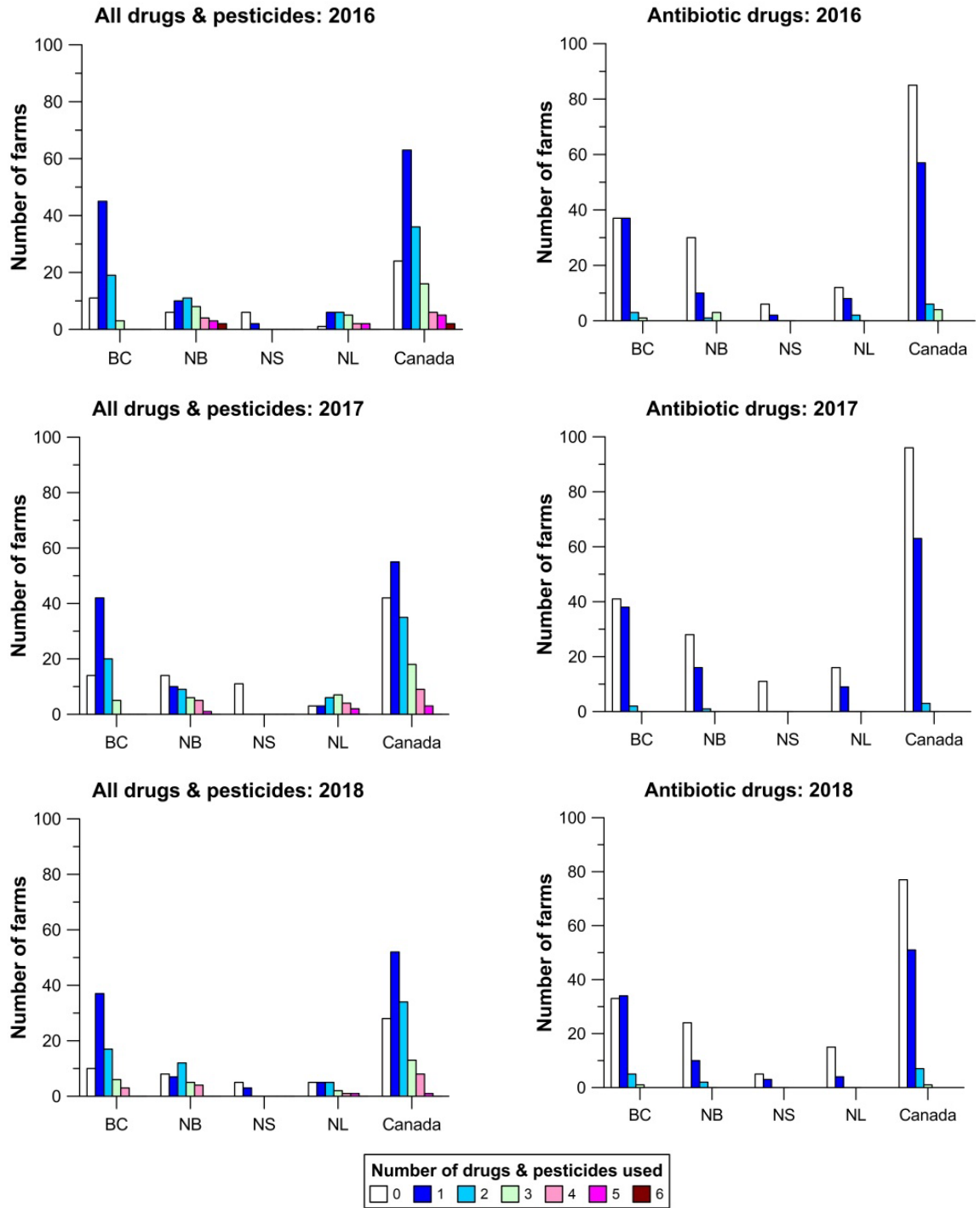

Figure 2. Numbers of Canadian marine finfish farms reporting the use of 0, 1, or more drugs and pesticides, per province, 2016-2018: all drugs and pesticides (left); antibiotic drugs (right). Data source: National Aquaculture Public Reporting Data marine finfish data (DFO, 2020).

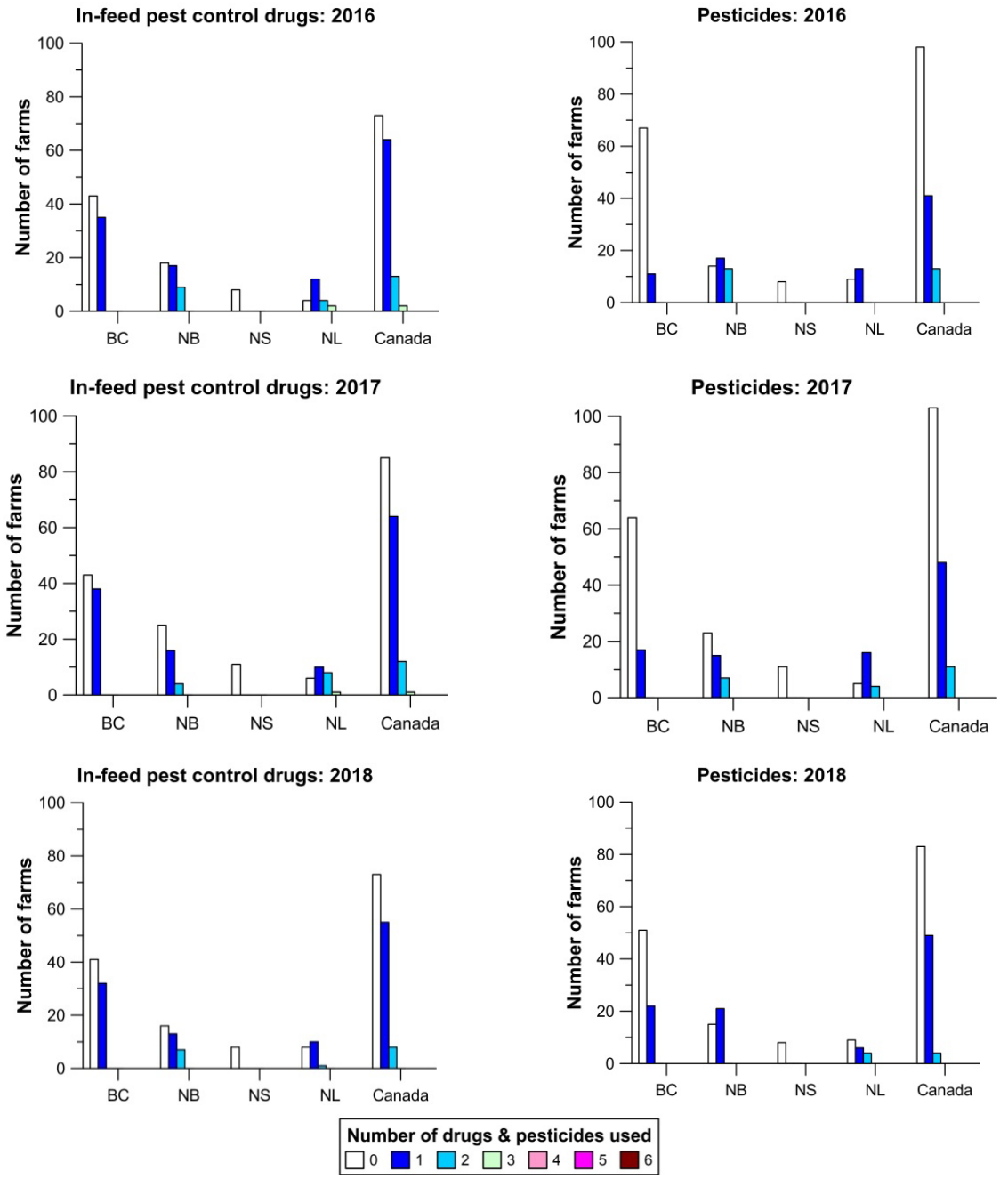

Figure 2 (cont'd). Numbers of Canadian marine finfish farms reporting the use of 0, 1, or more drugs and pesticides, per province, 2016-2018: in-feed pest control drugs (left); pesticides (right).

Summary of the Fate and Effects of Drugs and Pesticides used by Canadian Marine Finfish Aquaculture

The risk associated with the drugs and pesticides used in Canadian marine finfish aquaculture will depend, in part, on the potential environmental exposure that can result from their use at aquaculture sites. These chemicals can enter the aquatic environment in feces or other

excretions from treated fish, as deposits of uneaten medicated feeds, or diluted in seawater following release from tarps or well-boats. Environmental differences among regions, and among farm sites within regions, can greatly affect the fate and impact of these drugs and pesticides.

For a risk-based approach, the quantity of active ingredient that enters the environment is an important data input. This is dependent on the treatment concentration appropriate for the drug or pesticide being used, the size and number of fish, the treatment method and environmental conditions. For in-feed treatments, the quantity of treatment being administered will not be the amount that is subsequently excreted following metabolism. Therefore, any estimates of quantity of deposited or released in-feed treatment requires additional information on how the drug is metabolized, which can be dependent on the environmental conditions at time of treatment.

In-feed drugs that enter the marine environment through feces or uneaten feed are expected to be present in sediment, at the water/sediment interface, and/or in local biota. The persistence of the drugs or their metabolites vary greatly, depending on the specific drugs, the water temperature, sediment composition, and a variety of other factors.

Based on their chemical properties, the currently registered pesticides, which are released from tarps or well-boats after treatment, are expected to remain in the water column. The amount of time a pesticide remains in the water column depends on its half-life and adsorption characteristics. In addition, due to water dynamics, pesticides will disperse over time and space, further altering their location and concentration.

The following tables summarize information on the different antibiotics (Table 1), in-feed pest control products (Table 2), and pesticides (Table 3) approved for use in the Canadian marine finfish aquaculture industry. The information includes the reported objective for use of the particular drug or pesticide, and what is known about environmental fate (i.e., in sediments, water or biota) and biological effects. For more information about patterns of use, see Chang et al. (2021), that was presented as part of this process.

Table 1: In-feed antibiotic drugs used in marine finfish aquaculture in Canada, their reported use and information on environmental fate and toxicity to non-target organisms.

In-Feed Antibiotic Drugs	Reported Usage	Environmental Fate and Effect
Oxytetracycline	Broad spectrum antibiotic, active against infections of furunculosis, Vibrio, salmonid piscirickettsiosis (SRS),and Bacterial Kidney Disease (BKD). Annually, oxytetracycline was the most commonly used antibiotic drug by quantity with use varying regionally.	Oxytetracycline is delivered to salmon bound to food pellets. It can become bound to sediments, and may persist in the environment with decreased antibacterial activity (Armstrong et al., 2005). Once bound to sediment, oxytetracycline has a half-life of 150 days (Brooks et al., 2008). Oxytetracycline has low toxicity to crustaceans as it can be used to safely treat bacterial infections in lobsters (Bayer and Daniel, 1987).
Florfenicol	Broad-spectrum antibiotic used to treat salmon against	Florfenicol degrades in sediment with a half-life of 4.5 days

In-Feed Antibiotic Drugs	Reported Usage	Environmental Fate and Effect
	infections of furunculosis and yellow mouth. Annually, florfenicol is the most frequently prescribed antibiotic.	(Armstrong et al., 2005). Studies indicate that the toxicity of florfenicol is generally low (e.g., Florêncio et al., 2014; Basti et al., 2011).
Erythromycin	Macrolide antibiotic, used to treat gram positive and non-enteric gram-negative bacteria. It is used to treat Bacterial Kidney Disease (BKD). It is used at land-based facilities, injectable only for brood fish and not destined for human consumption. In BC, erythromycin may only be administered with an Emergency Drug Release from Health Canada's Veterinary Drug Directorate.	Erythromycin has a low toxicity to fish but can accumulate in sediments and organisms, and is a concern in terms of antibiotic resistance (Armstrong et al., 2005).
Sulfonamides (sulfadimethoxine and ormetoprim; sulphonamide and trimethoprim)	Broad spectrum antibacterial agents used to treat salmon infected with gram negative bacteria such as Vibrios and infections of furunculosis.	The environmental impact from the use of sulfonamides is unknown; however, given their broad spectrum activity and the fact they may be degraded slowly, their presence in the sediments may result in the development of antibiotic resistance (Armstrong et al., 2005).

From 2016-2018, the most predominantly used in-feed pest control drugs were the avermectins, which are effective in the control of internal and external parasites in a wide range of host species. Information on the different drugs, their reported usage as well as the environmental fate and effect, if known are summarized in Table 2.

Table 2: In-feed pest control drugs used in marine finfish aquaculture in Canada, their reported use and information on environmental fate and toxicity to non-target organisms.

In-Feed Pest Control Drugs	Reported Usage	Environmental Fate and Effect
Emamectin Benzoate (EB; avermectin)	Emamectin benzoate is effective in removing sea lice of all developmental stages. EB was the most used in-feed pest control drug.	Emamectin benzoate has the potential to be adsorbed to particulate material and will be tightly bound to marine sediments with little or no mobility (SEPA, 1999). Measurable quantities of EB (ppb) have been detected in sediments directly under an aquaculture site in British

In-Feed Pest Control Drugs	Reported Usage	Environmental Fate and Effect
		Columbia more than 1.5 years after the last application (DFO, 2012). The chemical action is non-targeted and may affect other non-target invertebrates when it reaches the environment (Willis and Ling, 2003). Studies indicate high toxicity of EB to non-target marine crustaceans (Willis and Ling, 2003).
Ivermectin (avermectin)	Ivermectin is routinely used in Atlantic provinces as a sea lice treatment only during the first year fish are in sea pens. Used in an “extra-label” manner as an anti-parasitic under a veterinary prescription.	Ivermectin has a low solubility in water and a strong affinity to lipid, soil, and organic matter (Tomlin, 1997); therefore, within the marine environment, it is expected to be associated with sediments and particles and to show low mobility (Davies et al., 1998). The chemical action is non-targeted and may affect other non-target invertebrates when it reaches the environment (Garric et al., 2007). Studies indicate high toxicity of ivermectin to non-target marine invertebrates (Garric et al., 2007).
Selamectin and abamectin (avermectins)	Similar application to ivermectin (also an avermectin); identified as active ingredients in anti-sea louse compounds. Selamectin was used in 2017 in New Brunswick on a trial basis.	Delivered via medicated feed, therefore may enter the marine environment either associated with uneaten feed or excreta (Samuelson et al., 1992, Kim-Kang et al., 2004). There are few data available on the toxicity of selamectin and abamectin to non-target marine species.
Lufenuron (moult inhibitor)	Lufenuron is a chitin synthesis inhibitor and classified as a growth regulator for animals with a chitin exoskeleton, preventing moulting. Therefore, it should prevent sea lice from getting to the adult stage. Used in hatcheries prior to smolt transfer under the Emergency Drug Release Program (DFO,	Following transfer into marine net-pens, lufenuron is deposited into the marine environment through excretions from treated fish (McHenery, 2016). Lufenuron has the potential to persist and bioaccumulate. It is adsorbed to particulate material and surfaces and will be tightly bound to marine sediments with

In-Feed Pest Control Drugs	Reported Usage	Environmental Fate and Effect
	2018), but is not authorized for treatments in marine environments.	little or no mobility. Similarly, the product should be tightly bound within the fatty tissue of the salmon (FDA, 2016). There are few data available on the toxicity of lufenuron to non-target marine species.
Praziquantel (antiparasitic)	Praziquantel is a synthetic heterocyclic broad-spectrum anthelminthic agent. In fish, it is usually used to treat against infestations of cestodes.	Praziquantel is rapidly metabolised by vertebrates. The parent compound rapidly degrades in seawater (Frohberg, 1984). There are few data available on the toxicity of praziquantel to non-target marine species.

In Canada two pesticides are registered for use in combating sea lice infestations on Atlantic salmon: hydrogen peroxide in Interox® Paramove 50® or in Aquaparox®, and azamethiphos in Salmosan®. Additional information on these two pesticides is summarized in Table 3.

Table 3: Bath pesticides used in marine finfish aquaculture in Canada, their reported use and information on environmental fate and toxicity to non-target organisms.

Bath Pesticides	Reported Usage and Mode of Action	Environmental Fate and Effect
Hydrogen peroxide	Used to treat infestations of both *Lepeophtheirus salmonis* and *Caligus elongates* at treatment concentrations of 1.5 g/L. Induces mechanical paralysis when bubbles form in the gut and haemolymph and cause the sea lice to release and float to the surface (Bruno and Raynard, 1994). As a drug, it is also authorized for the treatment of fungal infections of fish and their eggs in hatcheries.	Hydrogen peroxide is fully miscible in water and will remain in the aqueous phase upon entering the environment. It is unlikely to accumulate in tissue or sediment (ECHA, 2003). It has a half-life in seawater of approximately seven days or greater and degrades to oxygen and water (Haya et al., 2005; Lyons et al., 2014). Hydrogen peroxide is practically non-toxic to marine invertebrates and fish; however, it is highly toxic to marine algae (PMRA, 2014; Kavanagh, 1992).
Azamethiphos	Organophosphate insecticide. Neuro-toxic action, acting as an acetylcholinesterase (AChE) inhibitor. In the absence of AChE activity, nerves repetitively fire and the affected organisms eventually die.	Azamethiphos is likely to remain in the aqueous phase on entering the environment, and is unlikely to accumulate in tissue or in sediment (SEPA, 1997). It breaks down by hydrolysis in water with a half-life of 8.9 days,

Bath Pesticides	Reported Usage and Mode of Action	Environmental Fate and Effect
	Effective only against pre-adult and adult sea lice and has no effect on the larval stages. Sea lice sensitivity to azamethiphos is variable, and some sea lice populations are more sensitive to this compound than others. This has resulted in a need to treat cages repeatedly during periods of high infestation. Development of resistance to organophosphates is common and has been shown for azamethiphos.	and dispersion studies indicate that after release of an experimental treatment (200 $\mu g \cdot L^{-1}$ as Salmosan®), the concentration of azamethiphos was below detection (0.1 $\mu g \cdot L^{-1}$) in a short period of time (SEPA, 1997). Page and Burridge (2014) also reported the dispersion of azamethiphos to concentrations below toxic level effects in the order of minutes to an hour over spatial scales of 100s of meters to a kilometer. Azamethiphos is very highly toxic to marine invertebrates (via acute and chronic exposure), moderately to highly toxic to marine fish (via acute exposure), and poses a negligible risk to marine mammals and algae (PMRA, 2016).

Prior to being able to interpret the regulatory reports on treatments, or to be able to analyze or predict trends, the following data are required:

- drug and pesticide use per production cycle;
- information on the timing of stocking of fish into pens and biomass in relation to treatment dates;
- clarification as to whether treatments were for the whole site or part of the site (i.e., multiple reported treatments may reflect regulatory restrictions on the number of pens that can be treated per day); and
- size/configuration of sites that may influence the number of treatments.

Methods to Define Thresholds for Drug and Pesticide Residues in the Environment

There are a variety of methods available for establishing thresholds to align with the environmental protection objectives of the regulations. For the purpose of a post-deposit drug and pesticide monitoring program, one method is to align the thresholds with those used in the regulatory approvals process.

Thresholds can also be calculated following an Environmental Quality Standards (EQS) approach that integrates toxicity and impact data for the active ingredient, while explicitly accounting for scientific uncertainties associated with both the quality and quantity of toxicity data. This approach was chosen and implemented by the the Scottish Environmental Protection Agency (SEPA) for the management and monitoring of marine finfish aquaculture chemicals.

To determine EQS values, all available data must be considered, to avoid reliance on single toxicity endpoints that are not necessarily reflective of reality. However, the data are assessed by experts for both reliability and relevance. Reliability means that the inherent quality of the method used to conduct the test is high and that all relevant details to judge the performance and the results of the test are described. Relevance means the extent to which a test is appropriate to give insight on a particular question addressed. In data-poor situations, a deterministic rather than probabilistic approach is recommended, basing the EQS thresholds on the lowest credible toxicity data and applying an assessment or safety factor (ranging from 1 to 10 000) based on type of threshold (i.e., chronic or acute) and the number and type of available toxicity data (i.e., number of trophic levels and duration of toxicity studies). The Canadian Council of Ministers of the Environment (CCME) uses a deterministic approach to establish water quality guidelines.

Only reliable, relevant data should be considered valid for use in quality standard setting. Additionally, consistent with best practices (i.e., CCME Canadian Environmental Quality Guidelines, European guidelines for data-poor situations (TGD, 2018), and an overall weight of evidence approach), the biological, environmental, and data uncertainties need to be explicitly considered.

Depending on the chemical properties of the drug or pesticide active ingredient, it may be appropriate to determine different chronic and/or acute thresholds or EQS for water, sediments, and/or biota. In Scotland, both the acute and chronic water concentration EQS are intended to protect the structure and function of an aquatic ecosystem from the impact of chemical substances. For sediments, if there is an indication that the chemical accumulates in the sediment, then one sediment threshold or EQS per drug or pesticide is determined since benthic organisms will be constantly exposed in the sediments. Where sediment sampling is not possible, biota EQS for chemicals that bioaccumulate may be more appropriate. Similarly, thresholds or EQS addressing the concentration of a substance in biota may not be required if the physical and chemical properties of the active ingredient, along with any other information, suggest that the active ingredient is unlikely to remain in the tissues of organisms.

Substances that are highly hydrophilic with a short half-life are not conducive to environmental monitoring (whether in water or sediment).

In a Canadian context, the determination of thresholds or EQS values will need to be applicable to the range of marine environments where marine finfish aquaculture occurs, particularly related to sediment and substrate type. Therefore, it will be important that the regulatory thresholds (water, sediment, biota) align with the environmental protection objectives and the ability to assess those thresholds in the different environments. In setting thresholds or EQS for biota, there may be additional uncertainties as toxicity results may not be available for key Canadian species.

Modelling Exposure

Once thresholds for the allowable concentrations of treatment compounds detectable after their use at marine finfish aquaculture sites have been set, the sampling to be undertaken to ensure those thresholds are adhered to can be designed.

Modelling can estimate the likely shape and location of the mixing zones, the zones of exposure, and zones of potential impact resulting from the use of drugs and pesticides, which can then be used to help determine suitable sampling times and locations after treatments are undertaken. All models rely on simplifying assumptions; how well a given model represents a

specific situation will depend on the reasonableness of those assumptions. Model selection is dependent on the needed model accuracy and how the model output(s) will be used.

There are a range of transport, dispersion and deposition models, which predict the concentrations of in-feed drugs and bath pesticides found in the benthic environment and the water column. Each model requires specific inputs, including a range of parameters related to the drugs or pesticides, i.e., the amounts and specific chemical properties (including fate and effects) and oceanographic conditions.

Simple models provide order of magnitude estimates of predicted concentrations, depositional areas, and locations based on a limited number of inputs. More complex models incorporate more processes and spatial and temporal variability.

There are uncertainties associated with all inputs, and as more complex models have both more inputs and more assumptions than simple models, there are also more uncertainties and enhanced error propagation with complex model predictions. The existing more complicated models for predicting the dispersal, dilution and deposition of drugs and pesticides are still largely of uncertain precision and require more extensive evaluation and validation.

While there are few available models designed to predict releases of in-feed drugs and pesticides from fish farms, particle tracking deposition models for feed and feces can be useful for estimating the exposure zone of in-feed drugs. Simple deposition models often give reasonable order of magnitude estimates of the scale of near-field deposition. Using deposition models to predict exposure zones or concentrations of in-feed drugs has many associated uncertainties, including, for example, the relative proportion of drugs that are released as waste feed, feces or excretions and it is unknown how well they estimate far-field deposition.

The transport and dispersive processes around fish farms are generally complex in that they are spatially and temporally variable, and it is difficult to assess the accuracy of most hydrodynamic exposure models. The underlying assumption of most hydrodynamic models is that the release of pesticides produces a patch containing the treatment pesticide, which expands and moves with time. Simple models indicate that predicted exposure area, concentration, and location of the discharge patch depend on ambient currents, the treatment concentration and volume, and time since release. The Okubo and modified Okubo models have been validated for tarp and well-boat discharge estimates, see Page et al. (2015). Hydrodynamic models do not yet robustly incorporate the influences of cages on the near-field circulation and so their best use is for far-field predictions and have not been extensively calibrated nor validated.

The accuracy of model predictions is reliant on the information put into the models. This includes information on: treatment dosing strategies; the pharmacokinetics of the different drugs and pesticides; settling and deposition rates, degradation and bioavailability of pesticides and drugs in the marine environment; and fate of drugs and pesticides in the marine environment. There are also uncertainties within the models and how they incorporate different marine processes such as stratification, vertical mixing, wind-driven events (including storms), resuspension and redistribution of different sized particles (e.g., feed, feces, and flocs), and disaggregation and aggregation dynamics. Where uncertainties around the model inputs and the parameterizations are high, the accuracy of the model outputs will be negatively influenced.

Given the uncertainties remaining for all model types and the assumptions that must be made at this time for their use, empirical data and site-specific parameters will be needed to refine models and to enhance the accuracy of their outputs.

Before any model is used in the design of a monitoring program it needs to be properly validated for that use. While the mentioned uncertainties associated with model outputs remain, the use of model results in the design of a monitoring sampling program should be limited.

Sampling and Analysis

There are two different approaches that can be used in designing environmental sampling, and the choice depends on the objectives for the sampling. Probabilistic-based sampling involves a randomized selection of possible sample locations and sampling times, thus allowing for quantitative analysis, including uncertainty characterization. Judgement-based sampling uses existing knowledge of the area of interest by experienced and well qualified individuals to select sampling locations. This does not allow for statistical inference, but is useful for initial screening and scoping purposes and for screening for presence and absence. Judgement-based sampling is not ideal for supporting decision making or compliance purposes as quantitative confidence levels (i.e., uncertainties) cannot be associated with the results and the results cannot be extrapolated by inference to the overall or target population (US EPA, 2002). Probabilistic-based sampling is the preferred approach for supporting decisions and for compliance purposes.

A grid-based approach to probabilistic sampling may be appropriate for an aquaculture monitoring program. A grid-based sampling design consists of collecting samples in a specified spatial or temporal pattern. The approach is used to ensure that the target population is fully and uniformly represented, and that the full footprint of exposure is captured. This approach is well suited to exploring correlations between the measurements made on each of the samples. In a gridded approach, randomization of the sampling location is achieved by either randomly choosing the initial location of the grid or by randomly choosing the location of samples within each grid cell. Gridded sampling is appropriate for detecting hot spots, to estimate the size of features, and/or when measurements are correlated or exhibit a spatial or temporal pattern.

The choice of sampling design depends on the purpose for the sampling (i.e., to inform decisions, test for compliance, determining presence/absence of chemicals, etc.), the acceptable uncertainty limits, and the required resources to conduct the sampling. The resource considerations, including available personnel, time, and availability of financial resources, are primary drivers towards the choice of design. Together, these factors may lead to the consideration of a semi-probabilistic model, which uses probabilistic sampling points, but under judgement-based considerations.

In addition to using a suitable approach for the selection of sampling stations, the selection of timing and location for post-deposit sample collection should reflect factors such as the drug or pesticide release pathways, persistence and environmental fate.

The selection of appropriate sampling for bath pesticide discharges should take into consideration local hydrographic processes that result in plumes of pesticides that change in location and shape, increase in size, and decrease in concentration within hours. Sampling designs for detecting and characterizing the location, shape and size of pesticides with rapidly changing exposure and impact areas are challenging and not well established. Visible tracers (e.g., dye) can be used to tag bath pesticides, which can allow for targeted sampling within a few hours (0-5 hours) of bath treatment release.

Sampling design for in-feed drug discharges should take into consideration the ability to collect samples in addition to distribution pattern, temporal degradation and fate of both the active ingredients and metabolites. Existing sampling methodologies for the presence of drugs and pesticides in the benthic environment only allows for the analysis of sampled water, soft bottom

media (e.g., sand, silt, and mud) and benthic organisms collected through the use of sediment grabs or cores and divers. If the seabed area of interest does not consist of a suitable substrate, for example it is made up of rocks and boulders, a sample design requiring grabs and cores is unlikely to result in successful sampling for this area. The depth of sediment sample (e.g., 1 vs. 2 vs. 5 cm) is an important consideration, and there is uncertainty on the appropriate depth(s) for effective detection of those chemicals, their interpretation, and how unique events such as storms impact this depth. Knowledge of these details will impact the sampling strategies employed by a monitoring program. Having access to baseline data on the physical and chemical characteristics of the benthic environment will provide a better understanding of the area surrounding marine finfish aquaculture sites and can help to inform the sampling design.

The selection of appropriate methodologies for sample collection, handling and analysis requires consideration of:

- the chemicals to be measured (i.e., active ingredients, metabolites or degradation products);
- the regulatory thresholds and associated confidence limits;
- the environmental conditions;
- the substrates being sampled; and,
- analytical limitations (or analytical performance requirements); the appropriate selection of analytes will depend on the chemical properties of the drugs and pesticides in question, and their fate in the environment.

The selection of appropriate methodologies for sample handling, including storage and shipment, is required to ensure that the compounds of interest do not become degraded.

The establishment of analytical method criteria, including performance requirements, for the different compounds and matrices is essential for analytical consistency. While there are a number of analytical methods for the quantification of the active ingredients of in-feed drugs and pesticides, the application to marine environmental samples and for multi-class compounds is limited. Having established analytical criteria will allow for the validation and subsequent adoption of innovative methods, should they be fit-for-purpose.

Consideration must also be given to the chain of custody (i.e., to ensure the movement and handling of samples are tracked and recorded from collection to analysis) employed by field staff collecting samples as well as laboratory staff receiving the samples, as well as ensuring there is no accidental contamination or degradation of samples or analytical results. The requirements for documentation and chain of custody should also be included as part of both sampling and analysis standard operating procedures.

Regardless of the techniques used, for regulatory decision-making and enforcement, it is critical that the analytical method used for sample analysis has been demonstrated to give accurate data. Therefore, the use of validated methods is required and ideally, the laboratory analysis conducted in an accredited facility (e.g., ISO/IEC 17025) to give the client confidence that procedures employed by the laboratory will consistently follow a set of strict guidelines.

Assessing Antimicrobial Resistance (AMR)

Associated with the use of antibiotics is the potential for the development of antimicrobial or antibiotic resistance. The spread of antibiotic or antimicrobial resistance (AMR) is a natural

phenomenon in bacteria and comes from the propagation of antibiotic resistance genes (ARGs), or genes that code for a protein or function that will grant an organism resistance to an antibiotic or class of antibiotics. Early empirical studies have shown that ARGs are present in almost all bacterial populations sampled. Marine finfish farms and other points of organic accumulation, such as waste water treatment sites, can create large numbers of benthic bacteria, which grow and evolve quickly. Both the abundance and diversity of benthic bacteria and the relative frequency of ARGs vary with distance from these point sources of antibiotics in the environment.

Similar to designing sampling strategies to detect drugs or pesticides in the environment following use by the aquaculture industry, the history of antibiotic use at the site and the expected persistence of those antibiotics in the marine environment must be considered. Additionally, as AMR is naturally occurring in benthic bacterial communities, the background environmental levels of benthic bacterial communities and associated levels of naturally-occurring ARGs are important contextual information. AMR can be detected through the measurement of ARGs, and supplemented by secondary assays to assess the presence and level of AMR in the sampled bacteria. There remains significant knowledge gaps related to the ecological effects of antibiotic use around aquaculture sites, the potential pathways and reservoirs for the development of AMR, the non-target organisms impacted by the use of antibiotics and resulting AMR, the spatial and temporal ecological interactions of bacterial communities, and the background frequency of ARGs around marine finfish aquaculture sites.

Monitoring Program Considerations

As detailed above, the choice of models used, sampling design and analytical design are all dependent on the objectives they are intended to achieve. It is imperative that clear environmental protection and pollution prevention objectives are set by management before a post-deposit aquaculture drug and pesticide monitoring program that can be designed to achieve those objectives. This is critical to ensure that the collected data are at the appropriate spatial and temporal scale, are relevant and robust and can support management environmental risk decisions.

While advice was requested to inform the development of a program to include predictive modelling, mandatory mitigation, auditing and cumulative effects monitoring, the delivered advice can only be general in nature until the full objectives for the monitoring program have been determined and articulated.

Once the objectives of the monitoring program have been set, the multi-step process of designing the program can begin. As part of this process, consideration of how the resulting data will be used in management decisions and the required confidence limits for the data are both critical to the selection of the sampling and analysis design. The steps include an analysis of: (1) the hazards or toxicity associated with drugs and pesticides used for treatment at marine finfish aquaculture sites; (2) their environmental fate; (3) the patterns of drugs and pesticides use by industry over time; (4) the analytical limitations and associated variability in sampling and measuring parameters associated with these drugs and pesticides in different marine matrices (i.e., sediment, water, biota); and (5) the feasibility of sample collection (from both a technical and worker safety perspective). This information can be used to determine the relevant parameters that can be measured to address the objectives of the monitoring program, and to determine the associated scales of change that can be measured, thus contributing to the determination of thresholds of change for the monitoring program. Modelling can then be used to inform the sampling design, by predicting the likely shape and location of the mixing zones or the zones of influence resulting from the use of drugs and pesticides.

Thresholds can be selected to protect ecosystems by limiting the release of a particular chemical to levels that will not result in irreparable harm or toxicity to sensitive aquatic species. Exceeding the regulatory threshold will then signal potential biological impacts, but these can be confirmed only through direct biological monitoring. The biological indicators are ultimately the "early warning" signs of potential harm at the population level.

Once the modelling, sampling and analysis designs are chosen, the post-deposit monitoring program can be implemented and data generated. It will be important that monitoring data, along with scientific advancements and data generated elsewhere, be used to refine the program in the future, either at regularly scheduled time frames or associated with major advancements. To ensure that the program and its outputs are robust and informative, it will be essential that the program's requirements and quality standards are accessible and transparent. There should also exist standardized data reporting requirements, and data management must be thoroughly considered and implemented by the program.

Sources of Uncertainty

There are various sources of uncertainty associated with the available data and information, models, as well as known knowledge gaps. These will have different impacts on the different steps in developing or implementing a post-deposit monitoring program.

The uncertainties related to drugs and pesticides are:

- the inconsistent data on the use and release of drugs and pesticides due to a need for clarifying information requirements in treatment reporting under the AAR;
- the influence of the formulations of the drugs and pesticides on both environmental effects and fate;
- the pharmacokinetics of in-feed drugs resulting in errors in estimating the pattern and quantities that enter the environment through excretion;
- the transport, resuspension and redistribution, etc., of drugs and pesticides in the environment and how that affects sampling location and appropriate depth of sediment sample; and,
- whether the available toxicity data for each of the drugs and pesticides is representative of relevant species, in appropriate matrices, and at the relevant exposure durations.

There are considerable uncertainties associated with the temporal and spatial scales of antibiotic microbial resistance (or ARGs) in association with salmon aquaculture over background environmental levels. Current Canadian data are limited to a few sites in New Brunswick. The implications to human health through the food supply are unknown.

There remain analytical unknowns related to the appropriate methods for all matrices (water vs. sediment vs. biotia), chemical target (parent compound, degradation product and metabolites), and performance characteristics required for the analytical methods. Additionally, sampling protocols and sample handling (transport, stability and storage of samples in all matrices of concern) may introduce additional errors or uncertainties.

The robustness of the thresholds will be influenced by the methodology chosen, the strength of the available data, and it's applicability to the species and environment where it will be applied.

It is uncertain if chemical EQS will be protective of community structure in either the near or far-field. A biological or community EQS to complement a chemical EQS would provide information on this relationship.

The available models for both in-feed drug deposition and pesticide dilution and dispersion have many assumptions and associated uncertainties, and may require further validation. Some of the key uncertainties that can propagate additional errors within the model outputs include:

- the spatial and temporal representativeness of the current meter data;
- the representativeness of lab-derived parameters compared to how the chemicals react within the matrices and environmental conditions that occur in the marine environment; and
- influence of storm events on resuspension of particles and therefore appropriate sampling locations.

CONCLUSIONS AND ADVICE

To effectively design an appropriate monitoring program, clear environmental risk management objectives are essential. Once the management objectives of the monitoring program have been set, a range of possible monitoring strategies can be identified for further evaluation, selection and validation. The multistep monitoring program design process considers the hazards (e.g., chemical toxicities) and the environmental exposure (e.g., fate and pattern of use) of the drugs and pesticides of interest. These help to define and evaluate: (1) what is appropriate to be measured and aligned with program objectives; (2) thresholds; and (3) the level of confidence in assessing whether those thresholds have been exceeded. These thresholds can be designed in a variety of ways, including aligning with regulatory agencies, consistent with the development of benchmarks, and/or Environmental Quality Standards. When faced with a lack of data, thresholds can still be set using best practices, guidelines, and an overall weight of evidence approach. To account for scientific uncertainties and data quality and quantity, a correction or assessment factor can be applied.

The selection of appropriate models to support the design needs to consider the quality, quantity, and applicability of the available data. Standardized sampling, analytical methods, data reporting and management are required to allow for consistent data and interpretation.

Since the in-feed drugs (i.e., parasiticides and antibiotics) used in aquaculture will be present primarily in sediments and secondarily in water or the water/sediment interface and biota, a sediment-based and biota monitoring program for in-feed drugs is most appropriate. The active ingredient of these drugs and their metabolites can be persistent in sediments, but the duration varies by drug (i.e., from months to years). Deposition of drugs into the environment will be site-specific, and depositional models can provide estimates of drug concentration and location for identifying potential sampling stations.

The effect of the use of antibiotics on the marine bacterial communities in association with finfish aquaculture, as it relates to the development and impact of antimicrobial resistance, requires more study.

Conversely, bath pesticides enter the marine environment following release from tarps or well-boats; the currently registered bath pesticides are present primarily in the water column, dispersing and diluting away from the treatment location, which must be taken into account

when evaluating sampling designs for pesticides. Site-specific dispersion modelling can provide estimates of the dispersion and dilution over time.

A post-deposit monitoring program will generate additional data that, along with new scientific data including biological results, can be used to further refine the program over time.

Under the AAR, prior to administration the aquaculture owner/operator must first consider the use of alternatives to drug and pesticide treatments. This is an area of active research and emerging technologies. While some are in the R&D stage, others have widespread, commercial use, with ongoing optimization and refinements. There remain knowledge gaps related to efficacy, environmental interactions and fish welfare.

OTHER CONSIDERATIONS

A practical approach for a post-deposit monitoring program will need to account for varying local conditions. Additionally, these varying local conditions may be subject to changing climatic conditions. As a result of this high variability, a post-deposit monitoring program will need to be flexible in its application.

Periodic reviews of the monitoring program results and its elements should occur, in light of technological advances, new drugs and pesticides adopted by the industry, new research findings, monitoring results, and changing farm management approaches.

There are many sources of data held within a number of organisations and departments and collaborating in the analysis and assessment of these data can better inform the development, implementation, refinement and understanding of a monitoring program for drugs and pesticides.

Development of a post-deposit monitoring program should consider other existing environmental monitoring programs in Canada (national, regional, and provincial) and opportunities for their integration and/or alignment.

Other chemicals are used in aquaculture, such as disinfectants, anti-foulant agents and sedatives in both marine and freshwater facilities; as a first step in determining if they need to be monitored or not, use patterns should be reviewed. In some regions, information on these chemicals are already collected and reported.

This process did not review or provide advice on remediation measures to reduce or eliminate ecosystem impacts from the deposit of pesticides and drugs in the marine environment.

Information on the use of alternative approaches and mitigation measures and their efficiencies should be collected and related to drug and pesticide use patterns.

Refinement of operational procedures and future technological developments will contribute to furthering the mitigation of drug and pesticide use and impacts. This should be encouraged and would benefit from greater collaboration amongst all stakeholders.

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SOURCES OF INFORMATION

This Science Advisory Report is from the March 2-6, 2020 National Peer Review on Advice to inform the development of a drug and pesticide post-deposit marine finfish aquaculture monitoring program in support of the *Aquaculture Activities Regulations*. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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