ICES Journal of Marine Science, 58: 492–496. 2001
doi:10.1006/jmsc.2000.1034, available online at http://www.idealibrary.com on IDEAL®

Environmental impact of chemical wastes produced by the salmon aquaculture industry

K. Haya, L. E. Burridge, and B. D. Chang

Haya, K., Burridge, L. E., and Chang, B. D. 2001. Environmental impact of chemical wastes produced by the salmon aquaculture industry. – ICES Journal of Marine Science, 58: 492–496.

The rapid expansion of the salmon aquaculture industry in the last decade and the intentional and unintentional use of many chemicals have resulted in wastes that may have a direct environmental impact. Thus, methods and criteria are required to assess the environmental impact of these chemicals, in particular to identify the hazards and assess the risks of their uses. We describe a project in progress that is aimed at identifying the source of chemical wastes of salmon aquaculture in the Bay of Fundy, the quantities released, their distribution, and environmental fate. The project is also concerned with the effects of chemical wastes on important fisheries resources. Laboratory studies indicated that chemicals used in the treatment of sea-lice infestations are lethal to shrimp and lobsters. Lobsters exposed to sublethal concentrations of one of these chemicals, azamethipohos, had decreased reproductive success compared to control lobsters. However, more information is required to estimate the associated risk to wild populations of lobster and shrimp.

Key words: aquaculture, Atlantic salmon, biological effects, chemical wastes, ecotoxicology, sea-lice treatments.

Received 16 October 1999; accepted 15 March 2000.

K. Haya, L. E. Burridge, and B. D. Chang: Fisheries and Oceans, 531 Brandy Cove Road, St Andrews, NB, Canada E5B 2L9. Correspondence to K. Haya; tel: +1 506 529 5916; fax: +1 506 529 5862; e-mail: hayak@mar.dfo-mpo.gc.ca

Introduction

Salmon aquaculture is an important renewable resource industry in New Brunswick (Janowicz and Ross, 2001). The farm sites are concentrated in the southwestern Bay of Fundy (Figure 1). This area provides sheltered inlets and bays for cage culture, is relatively free of strong storm wave effects and has compatible water temperatures during winter. The industry has developed rapidly since the early 1980s and 92 Canadian and 33 American salmon aquaculture sites are now operating in this relatively small area. Most of the best, well-protected sites are occupied and there is great pressure to add more sites or to increase the number of fish at already existing sites. Last year the New Brunswick Department of Fisheries and Aquaculture instituted a fallowing strategy (most sites were without fish for periods of up to six months) to combat disease. This strategy has increased the pressure to license alternative sites.

We summarize a Department of Fisheries and Oceans project in progress on the effect of chemical wastes on indigenous animals and habitat near salmon cage sites. The study is carried out in the southwestern Bay of Fundy, but the results and methodology may be applicable regionally, nationally, and internationally. The information generated will find application in coastal zone management strategies and regulations related to the salmon aquaculture industry.

Wastes from salmon aquaculture now represent a major anthropogenic input in this area. They may be classified as organic or chemical. Organic wastes result from excess feed and faeces that may accumulate in the sediment and lead to eutrophication in the water column and anaerobic conditions in the sediment. Poor water quality and crowded conditions induce stress in caged fish and contribute to impaired growth and predispose them to disease. This, in turn, necessitates increased use of medicinals. For example, this area recently experienced sea-lice infestations and infectious salmon anaemia, a viral infection. Pesticides are being used to combat sea-lice infestations and disinfectants help to prevent the spread of the virus. These substances contribute to the input of chemical wastes to the environment, which may have a negative impact on human

1054–3139/01/020492+05 $35.00/0

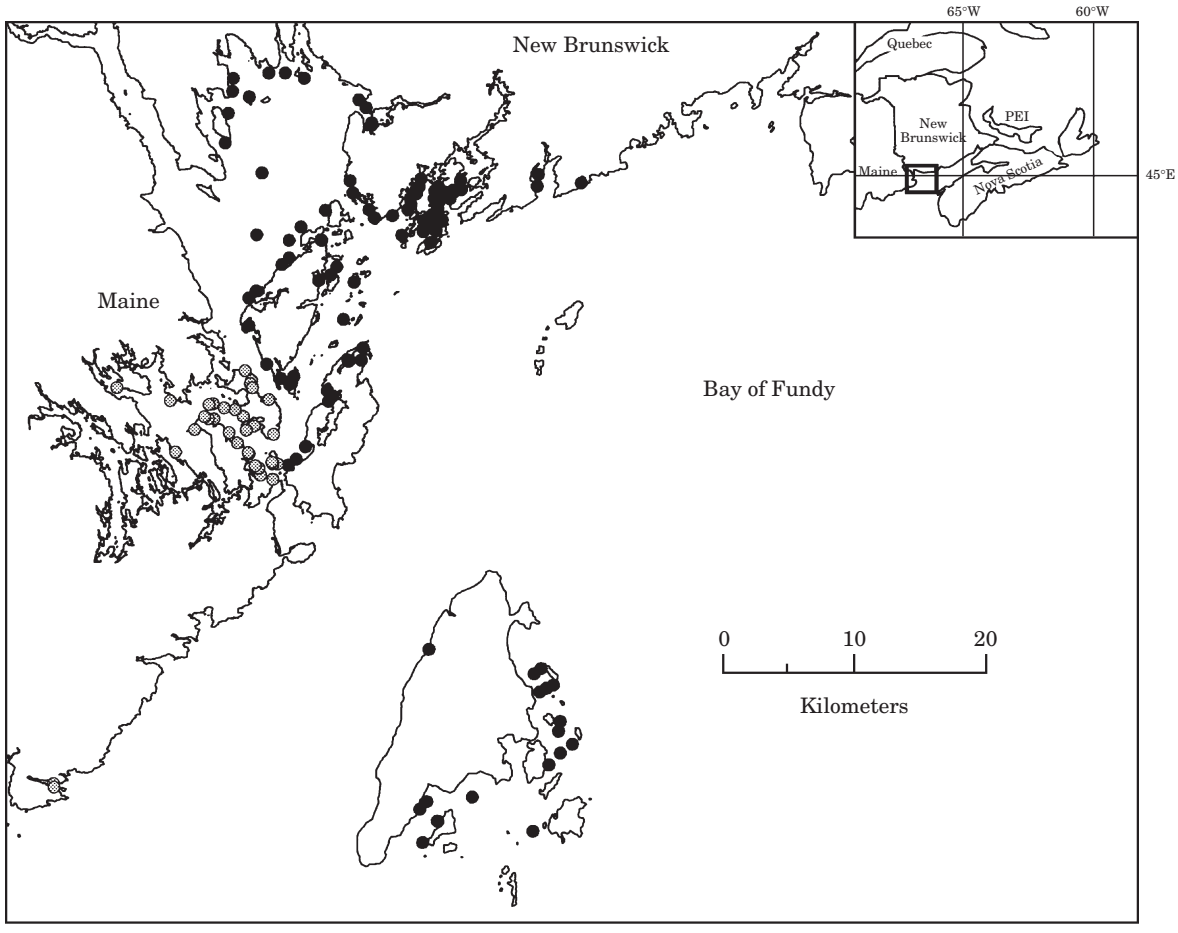

Figure 1. Licensed salmon aquaculture sites in southwest Bay of Fundy, 1999 (black dots: Canadian, grey dots: American).

health, health of the cultured species, habitat and indigenous organisms (Ervik *et al*., 1994; Rosenthal *et al*., 1993).

Little is known about the quantities, and often even about the identity, of the chemicals released into the environment. Many chemicals are used, both intentionally and unintentionally. In Canada, these include feed additives, chemotherapeutants, disinfectants, pesticides, herbicides, and antifouling agents (Zitko, 1994). With the rapid expansion of the industry in the last decade, the chemical wastes produced may now be a significant factor in its environmental impact. There has been considerable concern, suspicion, and uncertainty among fishermen and environmentalists in southwestern New Brunswick regarding the effects of these chemical wastes on local fisheries resources, indigenous species and fish habitat, but these are difficult to determine. Because of the need to develop methods and criteria to assess the environmental impact of the salmon aquaculture industry, our objective is identification of the hazard and assessment of the risk of chemical wastes produced. In addition, it is hoped that potential conflicts with other users may be addressed to provide a basis for improved protection of cultured and wild fisheries resources and their habitat.

The project is split into the following parts: identification of chemicals, their sources, and the quantities released; their distribution, environmental fate, and concentrations; and their effect on the ecosystem and important harvest fisheries resources. The studies on the source of chemicals and their fate and distribution are still in the initial stages and will be only briefly described.

Sources

Chemicals used in aquaculture may be introduced intentionally or unintentionally and fall into three general categories: food components, medicinals, and construction materials (Zitko, 1994). Fish oils (herring, shark), meals (fish, wheat, blood, poultry, canola, corn gluten), essential minerals, dyes, and antioxidants are added to fish feed. Pesticides, disinfectants, antibiotics,

chemotherapeutants, and anaesthetics are among medicinals commonly used. Construction materials include wood, plastics, paints, metal, antifoulants, and preservatives. The user usually knows the identity of intentionally added chemicals, but the identity and source(s) of unintentionally added chemicals are difficult to trace. The latter may include organochlorine pesticides, PCBs and other persistent chemicals in feed, chemicals in construction materials, and metabolites and degradation products of intentionally added chemicals. As a first priority, the project is focused on the identification and measurement of chemicals in feed.

Distribution and fate

The distribution and fate of the chemical wastes is largely unknown. Persistent chemicals may accumulate in sediment, as part of the excess feed or faeces sinking to the bottom. According to the industry, recent improvements in feeding technology have significantly decreased the amount of excess feed that falls through the cages. Less feed per kilogram of fish is required as new feed formulations and real-time video monitoring of feeding behaviour improve feed utilization. Consequently, the major waste seems to have changed from excess feed to faeces. Sediment samples have been collected in the depositional zone near and under cages in use and at fallowed sites. The samples are being analysed for the same suite of chemicals as present in fish food. The results will be used to deduce the source and the significance of the concentrations observed.

Because lobster harvest areas and holding pounds are in close proximity to salmon aquaculture sites, conflicts have arisen between the two industries. The potential of lobsters to accumulate chemical wastes from aquaculture operations is also being determined.

Biological effects

Recently, epidemic sea-lice infestations (parasitic copepods: *Lepeophtheirus salmonis* and *Caligus elongatus*) have caused significant losses to the industry. Infested fish have been treated with baths of hydrogen peroxide, pyrethrins, cypremethrin, dichlorvos, or azamethiphos. Also medicated feed containing ivermectin, emamectin benzoate, diflubenzuron, or teflubenzuron have been used, or are being considered for use. These anti-parasitic drugs require a prescription issued by a veterinarian. The bath treatments have received emergency, temporary registration for use in sea-lice treatments. Fish are isolated within a tarpaulin and sufficient chemical is added to the water to give the desired treatment concentration. After a bath for 30–60 min, the tarpaulin is removed and the solution is released into the environment. These pesticides and anti-parasitic drugs were developed and approved for land-based use at levels considered safe for mammals. Also, the efficacy and therapeutic indices for the treatment of sea-lice infestations of Atlantic salmon have been determined. However, many of these chemicals were used with no, or limited, information on their lethal and sublethal effects on other marine organisms, and information on their effects on the marine ecosystem is extremely limited. Here, some of our laboratory results are presented to illustrate the information that is needed in identifying the hazard and assessing the risk to other animals.

Table 1. The time (h) it takes for 50% mortality (LT50) in various marine invertebrates exposed to concentrations of azamethiphos (Salmosan®; NM = no mortality).

	Azamethiphos concentration ($\mu g\ l^{-1}$)		
	500	100	50
Green Crab	NM	NM	NM
Shrimp	1.58	8.50	8.50
Clams	NM	NM	NM
Scallops	NM	NM	NM
Lobster	0.17	0.71	1.2

Azamethiphos is an organophosphate insecticide and the active ingredient in the formulation Salmosan®. This is currently the only product approved for use in Canada by the Pest Management Regulatory Agency (Health Canada) for sea-lice treatment. It is used as a bath treatment at 100 $\mu g\ l^{-1}$ for 1 h at water temperatures <10°C and for 30 min at temperatures >10°C. Azamethiphos has neurotoxic action, acting as an acetylcholinesterase inhibitor. The acute lethality was determined for a number of invertebrate species (Table 1). The species selected are important to local fisheries and wild populations reside near aquaculture sites. Some belong to the crustaceans, the same class as sea lice. Under laboratory conditions, azamethiphos was toxic to lobster and shrimp but not to the two bivalves. The results indicate that 50% of the lobsters do not survive if exposed to azamethiphos concentrations used in bath treatments (100 $\mu g\ l^{-1}$) for less than an hour (Burridge *et al.*, 1999).

Pelagic larval stages of lobster may be present in and near cages during the season when sea-lice treatments normally proceed. We exposed different larval stages to formulations of azamethiphos, pyrethrins, and cypermethrin (Table 2; Burridge and Haya, 1997; Burridge *et al.*, 1999, 2000a; McLeese *et al.*, 1980). The bath concentrations used to treat sea-lice infestations are 100, 10, and 5 $\mu g\ l^{-1}$ for azamethiphos, pyrethrins, and cypermethrin, respectively. No differences in lethal concentrations were observed between larval stages and adult lobsters for azamethiphos and cypermethrin. However, there was a significant difference between the LC50 for Stage I, Stage II, and the rest for pyrethrins, and, unexpectedly, the earlier larval stages were more

Table 2. The lethal concentration (μg l^{-1}) of azamethiphos, pyrethrins, and cypermethrin for 50% mortality in larval stages and adults of American lobster after 48 h (LC50; from Burridge & Haya, 1997; Burridge et al., 1998, 2000a; * from McLeese *et al.*, 1980). Asterisk indicates significant differences from other life stages ($p<0.05$).

	Azamethiphos	Pyrethrins	Cypermethrin
Stage I Larvae	3.57	4.42*	0.18
Stage II Larvae	1.03	2.72*	0.12
Stage III Larvae	2.29	1.39	0.06
Stage IV Larvae	2.12	1.02	0.12
Adult	1.39		0.04*

resistant than the later stages. An evaluation of the cypermethrin data in conjunction with physical oceanographic techniques (scaling analyses) to estimate the dispersion rate of pesticides in the plume indicated that single anti-louse treatments are unlikely to result in lobster mortality (Burridge *et al.*, 2000a).

In reality, the rate of dispersion in the plume of treatment water released after bath treatments of salmon at cage sites is unknown and therefore it is difficult to assess the risk to resident lobsters. Also, at any one site there may be up to three treatments per day. Thus, indigenous organisms will not be constantly exposed to these chemicals but rather to pulses that probably vary up to a maximum of 2 h at 10% of the bath concentration (Burridge *et al.*, 2000a). To simulate this situation, we exposed Stage IV and adult lobsters repeatedly and for varying periods to one of two pesticide formulations (Burridge *et al.*, 2000c): Salmosan® (azamethiphos, currently in use) and Excis® (cypermethrin, under review for use). The exposures were equivalent to treating three cages a day for 3 d, which is a typical treatment regime at one aquaculture site. Thus lobsters were exposed for 15, 30, 60, or 120 min every 3 h for a total of nine exposures. Some of the stage IV lobsters appeared to be affected by these exposures, but only at the highest concentrations and longest exposure periods, and no deaths occurred. Exposure to concentrations equivalent to 10% or 25% of that recommended for sea-lice treatment for 15 or 30 min resulted in significant mortalities in adult lobsters. Adult lobsters exposed to Excis were affected over a wider range of concentrations and exposure times than those exposed to Salmonsan. The No Observable Effect Concentration (NOEC) for azamethiphos on adult lobsters was 1.03 μg l^{-1} when exposed for 120 min every 3 h, nine times. The NOEC for cypermethrin was 0.025 μg l^{-1} when exposed for 60 min under the same regime.

Bioavailability of a chemical to the organisms must also be considered. For example, ivermectin is a semi-synthetic derivative of a chemical produced by the bacterium *Streptomyces avermitilis*. It is effective in the control of internal and external parasites in a wide range of host species, particularly mammals. Ivermectin is used to treat sea lice under veterinary prescription and applied as an in-feed additive at recommended doses ranging from 50 to 200 μg kg^{-1} of fish d^{-1} for 2 weeks. Assuming fish are fed at 1% body weight per day, this is equivalent to the range of 5–20 μg ivermectin g^{-1} of food.

Sand shrimps (*Crangon septemspinosa*) were exposed to food containing various concentrations of ivermectin for 96 h in running water (Burridge and Haya, 1993). When the food was available to, and consumed by, the shrimp, mortality occurred. When the food was present in the water but not available, no mortality occurred, indicating that ivermectin was not absorbed from the water but was toxic to shrimp when medicated feed was ingested. The 96 h LC50 was 8.5 μg g^{-1} food, while the NOEC was 2.6 μg g^{-1} food. This indicates that Ivermectin is lethal to sand shrimp at concentrations below the recommended dosage. When we limited the exposure to only 2 h, then monitored the shrimp for 94 h, the 96 h LC50 was equivalent to a dosage of 190 μg kg^{-1} of fish d^{-1}, which is very close to the maximum recommended dosage. These results suggests that ivermectin-medicated feed in the doses used to treat sea-lice infestations are potentially harmful to sand shrimp. However, more information of the feeding behaviour and occurrence of sand shrimp near aquaculture sites has to be gained before the risk to wild populations can be assessed.

As part of a study on the effects of sublethal concentrations of azamethiphos on non-target organisms, female lobsters were stimulated to initiate spawning by manipulation of temperature and photoperiod. Then they were exposed biweekly to 10 and 5 μg l^{-1} of azamethiphos for 1 h for a total of five exposures (Burridge *et al.*, 2000b). The lobsters were observed for another 2 months, that is, until the expected end of spawning. The following is a summary of the results from two experiments, one that started in December 1997 and the other in March 1998. There was a significant reduction in spawning (successful extrusion and attachment of eggs to the swimmerets) of lobsters exposed to 5 and 10 μg l^{-1} of azamethiphos, 79% and 22%, respectively, compared to 95% in controls. Some of the lobsters that did not spawn in the treated groups died before their spawning period and others resorbed their oocyte vitellin. Those that did spawn produced the normal quantity of eggs and fertilization did not appear to be affected as all clutches reached the eyed stage. On lobsters that spawned normally, there were numerous clutches of eggs. The shell was light orange and the haemolymph was pale where visible. Of lobsters that were exposed to azamethiphos and did not spawn, none (or very few eggs) were found. The haemolymph and shell were black due to the resorbed oocyte vitellin. Again more information (for example oceanographic,

ecological, behavioral, physiological) is required to predict the field consequences of decreased lobster reproduction caused by azamethiphos in laboratory bioassays.

In conclusion, laboratory studies on the biological effect of some chemical wastes produced by the salmon aquaculture industry have identified potential hazards to indigenous organisms. However, much more research and information is required before the risk that chemicals used in treatment of sea-lice infestations pose to exploited populations, other species, and habitat can be assessed. The approach outlined seeks to identify hazardous chemical wastes and provides a start towards obtaining the information necessary for evaluating the risk and impact of aquaculture operations on the ecosystem.

Acknowledgements

We thank the following for valuable contributions and participation in the research projects presented: Dr Vlado Zitko, Susan Waddy, Ken Mckeigan, Monica Lyons, Dawn Sephton, Wifred Young-Lai, Sarah Mercer, Bette Hatt, Joy Wade, and Brenda Best.

References

Burridge, L. E., and Haya, K. 1993. The lethality of ivermectin, a potential agent for treatment of salmonids against sea lice, to the shrimp *Crangon septemspinosa*. Aquaculture, 117: 9–14.

Burridge, L. E., and Haya, K. 1997. Lethality of pyrethrins to larvae and post-larvae of the American lobster (*Homarus americanus*). Ecotoxicology and Environmental Safety, 38: 150–157.

Burridge, L. E., Haya, K., Zitko, V., and Waddy, S. L. 1999. The lethality of Salmosan (azamethiphos) to American lobster (*Homarus americanus*) larvae, postlarvae and adults. Ecotoxicology and Environmental Safety, 43: 165–169.

Burridge, L. E., Haya, K., Page, F. H., Waddy, S. L., Zitko, V., and Wade, J. 2000a. The lethality of the Cypermethrin formulation Excis® to larval and post-larval stages of the American lobster (*Homarus americanus*). Aquaculture, 182: 37–47.

Burridge, L. E., Haya, K., and Waddy, S. L. 2000b. The effect of azamethiphos on survival and spawning success in female lobsters (*Homarus americanus*). *In* Proceedings of the 27th Annual Aquatic Toxicity Workshop: October 1–4, 2000, St. John's, Newfoundland, p. 58. Ed. by K. C. Penny, K. A. Coady, M. H. Murdoch, W. R. Parker, and A. J. Niimi. Canadian Technical Report on Fisheries and Aquatic Sciences, 2331. 139 pp.

Burridge, L. E., Haya, K., Waddy, S. L., and Wade, J. 2000c. The lethality of anti-sea lice formulations Salmosan® (Azamethiphos) and Excis® (Cypermethrin) to stage IV and adult lobsters (*Homarus americanus*) during repeated short-term exposures. Aquaculture, 182: 27–35.

Ervik, A., Kupka Hansen, P., and Wennevik, V. (eds) 1994. Proceedings of the Canada–Norway Workshop on Environmental Impacts of Aquaculture, Institute of Marine Research, Norway. Fisken Og Havet, Nr 13: 135 pp.

Janowicz, M., and Ross, J. 2001. Monitoring for benthic impacts in the southwest New Brunswick salmon aquaculture industry. ICES Journal of Marine Science, 58: 453–459.

McLeese, D. W., Metcalfe, C. D., and Zitko, V. 1980. Lethality of permethrin, cypermethrin and fenvalerate to salmon, lobster and shrimp. Bulletin of Environmental Contamination and Toxicology, 25: 950–955.

Rosenthal, H., Hilge, V., and Kamstra, A. (eds) 1993. Workshop on Fish Farm Effluents and Their Control in EC Countries. Report of the Department of Fish Biology, Institute for Marine Science at Christian-Albrechts-University of Keil, Keil, Germany. 205 pp.

Zitko, V. 1994. Chemicals in aquaculture (an overview). *In* Proceedings of the Canada–Norway Workshop on Environmental Impacts of Aquaculture, Institute of Marine Research, Norway, pp. 97–106. Ed. by A. Ervik, P. Kupka Hansen, and V. Wennevik. Fisken Og Havet, Nr 13. 135 pp.