

Oil-adjuvanted furunculosis vaccines in commercial fish farms: a preliminary epizootiological investigation

Pete Smith, Maura Hiney *

Fish Disease Group, Department of Microbiology, National University of Ireland, Galway, Ireland

Received 15 January 2000; received in revised form 3 April 2000; accepted 3 April 2000

Abstract

An analysis is presented of some of the data available concerning the epizootics of furunculosis that occurred in commercial fish farms in Norway and Scotland between 1984 and 1995. The primary aim of these analyses was to establish the plausibility of the hypothesis that the introduction of oil-adjuvanted vaccines (OAVs) was the major factor that resulted in the ending of these epizootics. The limitations of the epizootiological data available are recognised and, as a consequence, the analyses are limited to a comparison of the time course of these epizootics and the timing of the introduction of OAVs. With respect to the Scottish data, the decline in the furunculosis epizootic was shown to have preceded the introduction of the OAVs. In Norway, there was a closer temporal coincidence between the introduction of the OAVs and the decline in the epizootic. There were, however, grounds for suspecting that at least some decline in the epizootic in Norway occurred before the introduction of OAVs in that country. It is argued that the assumption that OAVs were the cause of the decline in the furunculosis epizootics is unwarranted. It is also suggested that the general acceptance of the existence of this causal link has inhibited investigation of other factors involved in both the rise and the fall of these epizootics. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Vaccination; Furunculosis; Epizootiology; *Aeromonas salmonicida*; Aquaculture

* Corresponding author.

E-mail address: maura.hiney@nuigalway.ie (M. Hiney).

1. Background

In 1989, both the Scottish and the Norwegian Atlantic salmon farming industries experienced significant losses due to furunculosis in fish held in sea cages. By 1995, losses to this cause had reduced dramatically. In the early 1990s, oil-adjuvanted vaccines (OAVs) were introduced in both countries. Midtlyng (1996, 1998) has presented evidence that, under commercial farming conditions, these vaccines performed better than some previously available injectable and orally administered vaccines. It has been commonly suggested that the introduction of OAV was the major factor in the reduction of losses to this disease in both countries. It has also been suggested that the decline in these epizootics effectively provides a demonstration of the efficacy of these vaccines in the field. This note presents an examination of the validity of these hypotheses in the light of the available epizootiological data.

2. Introduction

2.1. *Epizootiology in commercial fish farming*

Any attempt at identifying factors playing a causal role in the epizootiology of fish diseases in commercial fish farming faces major difficulties (Jarp et al., 1994; Smith 1997). Some of these difficulties are associated with the characteristic response of fish farmers to disease or the threat of disease. When faced with a disease threat, fish farmers tend to introduce a number of management or husbandry changes. As the primary aim of fish farmers is to reduce mortalities and to increase profitability, this pragmatic, multi-faceted approach is entirely justified. For those, however, whose primary aim is to identify which of the management or husbandry changes might have been causally related to the reduction in mortalities, the existence of multiple changes presents a very significant problem. Research scientists can have difficulty identifying causal relationships in tightly controlled experiments in which only a single variable is changed between each experimental run. When a number of changes are made, frequently unquantified, some unquantifiable, many even unrecorded, then the difficulties of interpretation are manifold.

A further set of difficulties associated with the attempt to identify causal relationships from epizootiological data collected from a large number of commercial farms consists of those related to the quality of the available data on disease incidence. We are aware of no significant programs, operating during the relevant period (1984–1995), aimed at quantifying the extent of the incidence or the severity of losses to furunculosis in either Scotland or Norway. Data recording the percentage survival of smolts to market are available for these countries. These data do not, however, identify the causes of mortalities. The fact that in 1989, at the peak of the furunculosis epizootic in Scotland, only 58% of the smolts put to sea survived to market (Ellis, 1997) cannot, for example, be taken as evidence that 42% of these smolts died of furunculosis. In Norway, Jarp et al. (1994) have published a longitudinal study that provided information on the incidence of furunculosis. However, their study, which attempted to identify some of the

risk factors, was confined to the period April–October 1991. There was one program that collected quantitative data of the significance of furunculosis during the period 1988–1992. Ironically, this program operated in Ireland and during the period in question, no furunculosis epizootic occurred in this relatively small sector of the European salmon farming industry (Wheatley, 1994). This survey estimated that the total losses to furunculosis in marine farms in Ireland was 1% of smolt input.

2.2. *Limitations in the available data*

In this paper, we are attempting to compare, for Norway and Scotland, two sets of data; one set concerning OAV administration and one set concerning the incidence of furunculosis. The two sets are, however, not of the same quality with respect to their probable accuracy. The use of OAV in commercial fish farms can be estimated from the sales of the products produced by a limited number of manufacturers. Thus, it is reasonable to treat the data on the timing of vaccination used here as reasonably accurate.

The data we have obtained on the incidence of furunculosis must be treated as less trustworthy. These data were obtained from the laboratories assumed to have played a major role in the diagnosis of fish disease in each country. For Norway, the laboratory was the National Veterinary Institute, Oslo, and for Scotland, the SOAFED Marine Laboratory, Aberdeen. The Norwegian data were available as estimates of the annual number of farms identified as experiencing furunculosis outbreaks. These were published in the yearly reports of the National Veterinary Institute, Oslo and had been corrected for multiple sampling (Tore Håstein, personal communication).

For Scotland, the estimates of the number of outbreaks that occurred annually were available in the annual reports of the SOAFED Marine Laboratory, Aberdeen. There exists a real possibility, if not probability, that material was not sent the SOAFED laboratory from all outbreaks that occurred in the Scottish industry. It is, therefore, nearly certain that any estimate of the annual number of outbreaks made by this laboratory represents an underestimate of the actual incidence. The fact that this data set may provide an inaccurate estimate of the number of outbreaks in any year does not, however, mean that they must provide an inaccurate estimation of the time course of the epizootic. Provided that the percentage of the total number of outbreaks from which material is obtained does not change dramatically from year to year, then these data may well provide reasonable estimates of the relative numbers of outbreaks in sequential years.

There are a number of problems, other than their quantitative inaccuracy, associated with the data sets that we have employed in this paper. Neither the number of isolations nor an estimate of the number of outbreaks can legitimately be used as an indicator of the number of fish that died in the epizootic. Therefore, the data sets cannot be used as estimates of the severity of the epizootic. Further, as the data take no account of the total numbers of populations of fish present in any year, they cannot provide any estimate of the frequency of outbreaks. Thus, the data available from the National Veterinary Institute and the SOAFED laboratories cannot be used as direct or accurate measurements of many important parameters of the epizootics that occurred in each country. The

arguments presented in this paper are based, however, on the assumption that it is reasonable to use them as proxy indicators of the time course of these epizootics.

2.3. Analytical approach

Given the nature of the problems that are necessarily associated with an attempt at identifying any factor causally related to the decline of furunculosis in Norway and Scotland, we have given ourselves a more modest target. This note will be confined to a comparison of the timing of the introduction of OAV and the timing of the decline in furunculosis mortalities.

This approach is governed by the following simple and straightforward considerations. It is a logical necessity that a cause must precede its effect. In an epizootiological investigation, it can further be required that the time that elapsed between the putative cause and its postulated effect was reasonable in terms of the proposed biological linkage between them. In this type of argument, it should be noted that there is a logical asymmetry between proof and disproof. The demonstration that application of OAV preceded, by an appropriate time, the decline in the furunculosis epizootics would be consistent with the postulate that the vaccination played a causal role in the decline. It would not, however, provide conclusive evidence of such a causal relationship. In contrast, it is legitimate to argue that, to the extent that a decline in the epizootics preceded the vaccination, application of OAV cannot have been causally related to that portion of the decline.

This analytical approach will be applied to investigate whether the available data are compatible with the concept that the use of OAV in Scotland and Norway preceded a decline in the epizootic in those countries. Not only is this approach logical, but it also limits the meanings that may be attributed to the available epizootiological data

3. Analysis of field data

3.1. Norwegian data

The data on the furunculosis epizootic in Norway suggest that the epizootic started in 1987 and was effectively over by 1994 (Fig. 1). The year in which the epizootic reached its peak was 1991 when 398 farms were infected. In 1992, this number fell by 20% to 316 and in the following year, only 66 infected farms were recorded. Thus, the incidence in 1993 was 17% of that recorded in 1991.

Markestad and Grave (1997) have provided a chronology of the introduction of OAV in Norway. They state that “oil-adjuvanted vaccines became commercially available in Norwegian markets in the Autumn of 1992 although a limited volume had been used in field trials in 1991”. This would suggest that in 1992, the only fish at marine farms that had been vaccinated with OAV would have been post-smolts at a limited number of trial sites. The first large-scale use of OAV in Norway would have been to vaccinate the fish that were moved to sea during 1993 as post-smolts (Steinar Høie, personal communication). Thus, of the fish held in the majority of Norwegian marine farms during the 1993

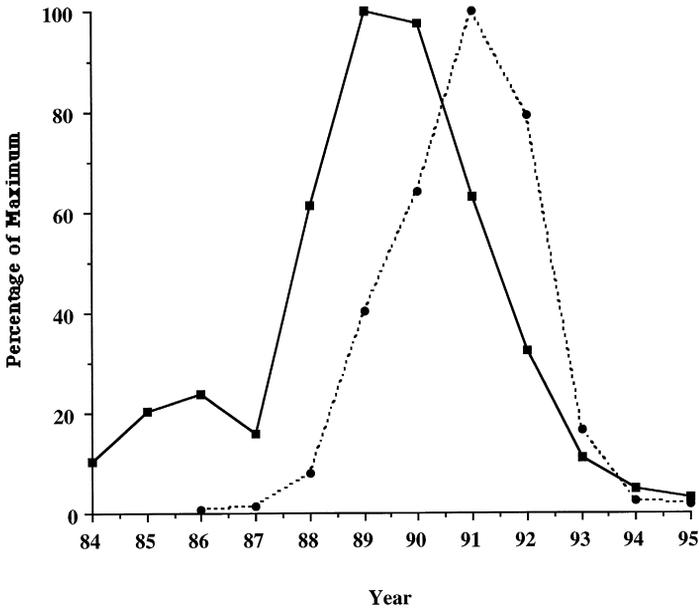


Fig. 1. Percentages of the maximum number of furunculosis outbreaks in Scotland (-■-) and Norway (-●-) between 1984 and 1995.

season, the first sea-summer fish (post-smolts) would have been vaccinated with OAV but the two sea-summer fish (growers), introduced to the sea in 1991, would not have been. Only by 1994 would all year classes of fish at the majority of Norwegian marine salmon farms have been vaccinated with OAV (Table 1).

Any comparison between these data on the timing of vaccination and the epizootiological chronology inherent in the available set of disease data is complicated by the failure of the disease data to differentiate between furunculosis in populations of post-smolts and those that occurred in growers. The estimates of the number of infected farms indicate, however, that there was a 20% reduction between the years 1991 and 1992. Only a very limited number of fish in Norwegian marine farms during 1992 would have been vaccinated with OAV. These OAV-treated fish would be those that were part of the limited trials undertaken in 1991 by Midtlyng (1996). In these trials, OAVs were only one of the range of prophylactic treatments compared at each site. As the disease data relate to farms and not individual net pens within a farm, it is unlikely that these trials would have reduced the number of outbreaks of furunculosis (Midtlyng, 1996). Neither the size of these trials nor their internal design would suggest that they could account for a reduction of 20% in the number of outbreaks. Thus, it is reasonable to accept the data as demonstrating that there was at least a partial decline in the furunculosis epizootic which preceded OAV treatments even of the post-smolts. The decline that started in 1992 continued in 1993 with the number of infected farms in 1993 being less than 21% of the number identified in 1992. This dramatic decline in infected farms

Table 1

Number of *Aeromonas salmonicida* isolations and estimated number of furunculosis outbreaks in Norway between 1984 and 1995

Year	Estimated outbreaks ^b	Estimate of fish vaccinated with OAV in Norwegian marine farms
1984		None
1985		None
1986	3	None
1987	6	None
1988	32	None
1989	160	None
1990	255	None
1991	398	None
1992	316	Few post-smolts ^a ; no growers
1993	66	Most post-smolts; some growers ^b
1994	10	Most post-smolts and growers
1995	7	Total availability

^aIn 1992, only a few post-smolts that had taken place in a limited number of trials were vaccinated with OAV (Midtlyng, 1996).

^bThere was significant vaccination of growers at sea during 1992–1993. This re-vaccination involved the use of water-based vaccines (Steinar Høie, personal communication) and is, therefore, not relevant to the arguments presented here.

occurred when, at the majority of farms, post-smolts would have been vaccinated with OAV but growers would not have been. Thus, with respect to post-smolts, the use of OAV preceded the major decline in the epizootic. With respect to any furunculosis outbreak that occurred in growers, however, this temporal relationship does not hold. Logically, therefore, the use of OAV cannot be directly causally related to the decline in outbreaks in growers in 1993. A possible indirect causal linkage could, however, be imagined. To the extent that furunculosis in two sea-summer fish was *itself* a consequence of the presence of the disease in the younger fish, then the treatment of the younger fish with OAV could have had an indirect effect on the fate of the older year class. Experience of individual epizootics would suggest that this indirect effect is a plausible hypothesis. Our inability to obtain any quantitative datum relevant to this issue serves to underline once again the importance of detailed routine collection of epizootiological data.

The question being addressed in this paper is whether, having considered the chronologies of the epizootic and the vaccinations, there are sufficient grounds for rejecting the hypothesis of a causal role for OAV. The above analyses demonstrate, on one hand, that the major decline in the furunculosis epizootic occurred in the year when, for the first time, the majority of post-smolts had been treated with OAV. On the other hand, it must be noted that a very significant decline in the epizootic had occurred before all year classes in the farms had been vaccinated with OAV. Further, it is highly probable that some decline, possibly as great as 20%, occurred before any widespread use of OAV had occurred at all. Given this degree of ambiguity, it would probably be unwise to demand a complete rejection of the causal hypothesis. It would be equally

Table 2

Estimated number of furunculosis outbreaks in Scotland between 1984 and 1995

Year	Estimated outbreaks	Estimate of fish vaccinated with OAV in Scottish marine farms
1984	13	None
1985	26	None
1986	30	None
1987	20	None
1988	78	None
1989	127	None
1990	124	None
1991	80	None
1992	41	None
1993	14	Most post-smolts; few growers
1994	6	Most post-smolts and growers
1995	4	Total availability

unwise to believe that this comparison of chronologies does not raise some doubts as to the validity of such an hypothesis.

3.2. Scottish data

The data on the furunculosis epizootic in Scotland have been collected from SOAFED. These data were available in terms of the estimated number of outbreaks identified. These data, presented in Fig. 1, indicate that the furunculosis epizootic in Scotland reached a peak in the summers of 1989 and 1990 when 127 and 124 outbreaks were identified. The number of outbreaks fell steadily from 1990 and by 1992, only 41 outbreaks, 32% of the peak 1989 number, were identified. The 14 outbreaks identified in 1993 represented a reduction of 89% from those recorded at the peak of the epizootic.

Robin Wardell of Aquaculture Vaccines has provided an estimate of the chronology of the introduction of OAV in Scotland (Table 2). He states that OAVs were introduced in time to vaccinate the smolts that were transferred to sea in 1993. Again it should be noted that fish in their second sea summer during 1993 would not have been vaccinated with OAV and only by 1994 would it have been possible for all fish to have been treated with OAV.

With respect to the Scottish data, it is clear that a significant percentage of the decline in the mortalities (68%) occurred prior to the 1993 season (Fig. 1). There is, therefore, no doubt that this component of the decline preceded the vaccination with OAV. Thus, rejection of any hypothesis which postulates that the use of OAV caused the reduction in mortalities and the decline of furunculosis in Scotland is logically unavoidable.

4. Conclusions

As stated at the outset, the quality of the available data requires that the aim of this paper be limited. It would be totally illegitimate, from the data presented, to attempt to

construct a proof of the causal role of OAV. Any analysis must be limited to the demonstration that such a causal role is or is not consistent with the available facts. From the consideration of the data presented here, the following would appear to be logically necessary conclusions.

(1) With respect to the data collected from Norway, it would seem probable that at least some of the decline in the epizootic preceded the use of OAV in post-smolts. Further, the epizootic was nearly over before the majority of the growers in marine farms could have been treated with OAV. Thus, the comparison of these relative chronologies must raise questions as to the validity of the hypothesis that vaccination with OAV was the primary causal factor in the decline of the national furunculosis epizootic. It would be an overstatement to suggest that the Norwegian data present an irrefutable case for rejecting the causal role.

(2) The data collected from Scotland clearly demonstrate that a very significant decline in incidence of furunculosis in the Scottish industry preceded the introduction of OAV even for post-smolts. Thus, the hypothesis that OAV played a causal role in the decline of the Scottish furunculosis epizootic must be rejected.

(3) Following a consideration of the Scottish data, it is logically necessary to postulate that the operation of a factor or a combination of factors not including OAV can result in the dramatic decline of furunculosis in a national industry.

(4) There are no reasons for eliminating the possibility that some of factors, whose operation in Scotland led to the decline in furunculosis incidence, were also operating in Norway during 1993. Thus, OAV is only one of the possible reasons for the decline in furunculosis in Norway between 1992 and 1994.

(5) The demonstration that the use of OAV was not causally related to the decline of furunculosis in Scotland is not the same as stating that OAV is not efficacious in the control of furunculosis. All that logically follows from the analysis of the Scottish data is the conclusion that neither the Norwegian or the Scottish data can be used to provide evidence of such efficacy.

(6) It should be noted that non-OAV vaccines were available for the control of furunculosis prior to the introduction of the OAV. The discussions presented here do not address the possible significance of these vaccines in the decline of the two epizootics.

5. Postscript

In the introduction to this paper, two questions were posited. Can the decline in losses to furunculosis, experienced in both Scotland and Norway during the early 1990s, be used as evidence for the efficacy of OAV? Was the introduction of OAV the major factor in the decline of these epizootics? The answer to the first is no, but the answer to the second lies somewhere between probably not, if the data from both countries are considered, and definitely not, if the Scottish data are taken on its own. These conclusions, themselves, raise a further serious question. If OAVs were not the major cause of the decline, what factors were? The nature of these factors remains to be elucidated. In any attempt designed to identify the factors that led to the decline in the epizootic, it would be important not to ignore the related question of which factors led to the development of the epizootic in the first place.

It is important to stress that this paper has confined itself to an epizootiological investigation of the impact of OAV. Thus, the arguments cannot be extended to cover the impact of any other vaccines.

Acknowledgements

The authors wish to thank Dr. Steinar Høie, Norway, for his help in the preparation of this manuscript.

References

- Ellis, A.E., 1997. Immunisation with bacterial antigens; furunculosis. *Fish Vaccinology* 89, 107–116.
- Jarp, J., Gjevre, A.G., Olsen, A.B., Bruheim, T., 1994. Risk factors for furunculosis, infectious pancreatic necrosis and mortality in post-smolt of Atlantic salmon, *Salmo salar* L. *Journal of Fish Diseases* 18, 67–78.
- Markestad, A., Grave, K., 1997. Reduction of antibacterial drug use in Norwegian fish farming due to vaccination. *Fish Vaccinology* 90, 365–369.
- Midtlyng, P.J., 1996. A field study on vaccination of Atlantic salmon (*Salmo salar* L.) against furunculosis. *Fish and Shellfish Immunology* 6, 553–565.
- Midtlyng, P.J., 1998. Evaluation of furunculosis vaccines in Atlantic salmon. Experimental and field studies for assessment of protection and side effects. PhD Thesis, National Veterinary Institute, Oslo, Norway.
- Smith, P., 1997. The epizootiology of furunculosis: the present state of our ignorance. In: Bernoth, E.-M., Ellis, A.E., Midtlyng, P.J., Olivier, G., Smith, P. (Eds.), *Furunculosis: Multidisciplinary Fish Disease Research*. Academic Press, London, pp. 25–53.
- Wheatley, S.D., 1994. Epidemiological investigations of Atlantic salmon production using a computerised database system. PhD, Queens University, Belfast.