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Short Communication

The global economic cost of sea lice to the salmonid farming industry

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The economic cost of a problem may be the best metric for prioritizing research and management resources. Other metrics could be based on fish welfare, and risks or impacts of parasiticides on the environment, farm staff or the consumer; but these are not addressed here. Sea lice, ectoparasitic copepod crustaceans, are the most damaging parasite to the salmonid farming industry in both Europe and the Americas (Costello 2006). Despite major research efforts over 30 years, as evident from over 800 research publications, they remain a persistent problem. The damage includes the impact on the fish and the environment, and public perceptions of aquaculture (Costello 1993; Pike & Wadsworth1999; Costello, Grant, Davies, Cecchini, Papoutsoglou, Quigley & Saroglia 2001). However, their economic cost has only been estimated at national or regional scales. Here, published estimates of sea lice costs are presented to stimulate better estimates, and provide an estimate of sea lice costs to the world salmonid farming industry.

Estimated costs of sea lice control were obtained from the literature (Table 1) and compared with the most recently available salmonid production statistics (Table 2). The salmonid data used included marine production of Atlantic salmon, *Salmo salar* L., Pacific salmon species, *Oncorhynchus* spp., sea trout, *Salmo trutta* L., and charr, *Salvelinus alpinus* (L.), from countries where sea lice have been reported to be a problem. Data were excluded for countries where sea lice have not been reported as a significant problem, namely Australia, Finland, France, Iceland, Japan, New Zealand and Sweden. To calculate costs per region, average costs from Table 1 were used for UK (Scotland), most recent cost for Norway, Norwegian cost for Faeroes, average of Atlantic Canada for all of Canada and USA, and only the full cost for Chile. These costs were then multiplied by the 2006 marine salmonid production to calculate costs per country and globally (Table 2). Costs of sea lice control are reported in the original currency but converted to cost per kilogram of fish produced by country. For comparative purposes, all values were converted to euros (€) in April 2008 to minimize the effect of recent changes in the value of the US$.

Ten estimates of costs because of sea lice were obtained from eight publications for Canada, Chile, Ireland, Norway and Scotland (Table 1). However, what costs the estimates included was only reported in five publications. Whether costs varied between Pacific and Atlantic Canada, and what they were for the USA, were not available. The lowest and highest estimates vary by a factor of 100 for full lice costs, and by 1000 where lower estimates only considered treatment expenses. These differences reflect the different costs between parasiticides and for the same parasiticides between countries, and to a lesser extent price changes over time. Most estimates fell within the range of €0.1–0.2 kg^{-1} fish produced annually.

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Table 1 Published estimates of the cost of sea lice to salmon farming including parasiticide use, effects on fish growth, and food conversion; except where not stated (*), or where stated to be for treatment costs only (**)

Cost	Lower (€ kg^{-1})	Upper (€ kg^{-1})	Country	Year	Source
£0.153–0.230 kg^{-1}	0.196	0.294	Scotland	2000	Rae (2002)
US$0.3 kg^{-1}	0.194	–	Chile	? 1997	Carvajal *et al.* (1998)
*1.503 Kr kg^{-1}	0.185	–	Norway	1997	Pike & Wadsworth (1999)
*£0.134–0.269 kg^{-1}	0.172	0.344	Scotland	1998	Pike & Wadsworth (1999)
£0.123–0.261 kg^{-1}	0.157	0.334	Scotland	? 1997	Sinnott (1998)
*IR£0.08–0.10 kg^{-1}	0.102	0.127	Ireland	? 2000	Anon (2003)
*0.103 Kr kg^{-1}	0.013	–	Norway	? 1993	Maroni *et al.* (1994)
Can$0.13–0.18 kg^{-1}	0.082	0.114	Atlantic Canada	? 2000	Mustafa *et al.* (2001)
**US$0.004–0.022 kg^{-1}	0.003	0.014	Chile	? 2002	Bravo (2003)
*Can$0.470 kg^{-1}	–	0.298	Canada	1995	Pike & Wadsworth (1999)

Table 2 Estimated costs of sea lice control based on 2006 salmonid production statistics (FAO Fisheries and Aquaculture Information and Statistics Service 2008)

Country	Production (tonnes)	Value (thousands US$)	Cost sea lice control € kg^{-1}	Total cost €
Norway	689 970	2 649 930	0.19	131 094 300
Chile	647 445	3 839 713	0.19	123 014 550
United Kingdom	134 521	669 700	0.25	33 630 250
Canada, Pacific	70 178	392 333	0.10	7 017 800
Canada, Atlantic	47 880	267 675	0.10	4 788 000
Faeroes	18 574	92 878	0.19	3 529 060
Ireland	11 720	69 008	0.11	1 289 200
Maine, USA	9 401	37 510	0.10	940 100
Total	1 629 689	US$8 018 748	Median 0.19	305 303 260

The analysis assumed that sea lice control costs increased in proportion to production. In the past five years, production increased in all countries except Faeroes, Ireland and USA where it significantly decreased. Because over 70% of world production was from Norway and Chile, production and sea lice control costs in these countries had the greatest contribution to global costs. Multiplying the sea lice costs by the FAO Fisheries and Aquaculture Information and Statistics Service (2008) salmonid production figures for 2006, indicated a total cost of €305 million, or US$480 million at present currency exchange rates (Table 2).

While the sea lice control estimates and production statistics used were the most recently found in scientific publications, they may not reflect current costs. Because the basis of earlier and more recent estimates were not reported, it was not possible to determine how sea lice control costs have changed over time. However, as profit margins get narrower because of increased competiveness as the industry develops, fish-feed costs increase, and farms are under pressure to control lice to prevent spread to wild fish and other farms, it seems likely that sea lice control remains a significant limitation on farm profitability.

The absence of reports of sea lice problems in several countries merits study. It does not seem to be because of the absence of sea lice species. The salmon louse, *Lepeophtheirus salmonis,* occurs on wild salmonids around Japan, and *Caligus* species occur worldwide. While *L. salmonis* is absent in the southern hemisphere, *C. rogercresseyi* has become the pathogenic species on salmonid farms in Chile, *Caligus chiastos* Lin and Ho on bluefin tuna, *Thunnus maccoyi* (Castelnau), in South Australia (Hayward, Aiken & Nowak 2008), and *C. epidemicus* Hewitt has been pathogenic to a range of wild and farmed finfish species from Australia to south-east Asia.

Limited production may not provide the opportunity for sea lice epidemics to develop. This may explain the absence of a sea lice problem on salmonids in Denmark, France, Germany, Iceland, New Zealand, Russia, Spain, Sweden and Turkey, where each country's production was <8000 tonnes p.a. in 2006 (FAO Fisheries and Aquaculture Information and Statistics Service 2008). Salmonid production in Australia and Finland is 20 000 and 10 000 tonnes, respectively, but is in brackish waters which are less suitable for sea lice. In addition, the short duration of the sea growing period in Japan (12 000 tonnes p.a.) prevents lice populations becoming significant on farms (Nagasawa 2004). Alternatively, perhaps it is not total production, but the number and density of farm sites that is significant in limiting the development of sea lice epidemics. Further research to understand why lice are not a problem in some regions would be useful in developing methods to reduce the risk of sea lice, and perhaps other pathogens, in sea cage farming in currently affected and unaffected countries.

It may be anticipated that there would be significant differences in control costs between countries (Table 1). Not only may staff and other operational costs vary between countries, but so can treatment availability, and there may be significant differences in the details of how costs were calculated between studies (Table 3). The costs in terms of compromised health, negative publicity from uses of parasiticides (Costello *et al.* 2001), and economic consequences of cross-infection to wild fish, were not quantified in the studies, and would be additional (Table 3). Indeed, if sea lice from farms have been significant in precipitating the collapse of wild salmonid populations in Europe and Canada as recent data indicates (Ford & Myers 2008), then the economic costs of sea lice are far greater than those presented here.

The most significant costs of sea lice where control is successful in preventing pathogenicity, are treatment costs, reduced fish growth, and reduced food conversion efficiency (Table 3). Further data to enable comparison of the effects of different control methods on fish growth and food conversion efficiency would enable more accurate estimates of the costs of control options. Comparisons between treatment options by Peddie (in Pike & Wadsworth 1999) in Scotland found an in-feed treatment cost less than bath treatments because of the latter requiring more staff time and equipment, and being more stressful to the fish. Using cleaner-wrasse was the next cheapest option after the in-feed treatments. However, the amount of wrasse could have been halved and how their efficacy was determined was not stated; over time, wrasse are more efficacious in removing lice than bath treatments (Treasurer 2005; M. J. Costello, unpublished data). In contrast, Mustafa, Rankaduwa & Campbell (2001) compared two bath with one in-feed treatment and found the latter more expensive. It must be appreciated that new parasiticides tend to be more expensive than established ones, especially if the latter were widely used in other areas of veterinary medicine. Furthermore, while there is a close relationship between in-feed parasiticide costs

Table 3 A ranked importance of impacts of sea lice on the profitability of salmonid farming where control measures prevent pathogenicity

Rank	Impacts	Significance if sea lice control effective
1	Purchase costs of parasiticides Purchase and maintenance costs of equipment Staff time in research, management and control	17–30% (Mustafa *et al.* 2001; Rae 2002) of total lice control costs
2	Reduced fish growth	5–15% smaller weight (Sinnott 1998; M. J. Costello, unpublished data)
3	Reduced food conversion efficiency	5% more feed required (Sinnott 1998)
4	Reduced marketability because of disfigurement by lice	1% fish downgraded in Atlantic Canada (Mustafa *et al.* 2001) and up to 15% in Scotland (Michie 2001)
5	Stress and accidental mortalities because of parasiticide treatments	Only significant for bath treatments and included in above costs
6	Negative publicity from the use of parasiticides that may leave residues in fish fillets, and/or are released into the coastal environment Negative publicity and perhaps increased control required where farms may act as sources of sea lice that cause mass infestations (epizootics) that impact on wild fish populations of commercial, recreational, and/or cultural value	While an estimate could be derived from the price premium of organic salmon, such production is negligible globally
7	Losses because of secondary infections	No evidence for significant transmission of pathogens by sea lice, and if controlled, damage to host skin will be minimized
8	More expensive farming practices	Preventative measures also minimize transmission of other pathogens, so this is considered a cost of business
9	Fish mortality	< 1% (as non-pathogenic)

and fish weight, that for bath treatments depends on sea-cage size, which has a more variable relationship to fish weight. Thus, the choice of the most cost-effective control method must be calculated in the context of the farm operational costs, and costs of methods available to the farm at the time.

There are several species of sea lice in most countries farming salmonids, and they have several wild hosts. Thus a reservoir of lice will always be present around the farms. As new species are cultured and production increases, it may be only a matter of time before sea lice similarly infect them. Research into the ecology of other sea lice species, and understanding of how epidemics develop and persist, will enable the development of strategies to reduce the risk of sea lice impacting on current and emerging farmed finfish. Research and management measures to avoid farm infection from other farms and wild fish, and cultured fish that are lice resistant (e.g. on which lice cannot reproduce), whether mediated by genetic breeding or diet, may be the best strategies to reduce annual costs to the industry.

In 2006, total salmonid marine production was 1.7 million tonnes worth US\$8.4 billion (FAO Fisheries and Aquaculture Information and Statistics Service 2008). Available data indicates sea lice cost from €0.1 to €0.2 kg^{-1} of fish (Table 1). However, without such treatment measures, sea lice would cost the industry at least four times more (Mustafa *et al.* 2001), and probably increase to levels such as to cause significant direct and indirect mortality to stock. Regional estimates for the cost of sea lice ranged from 4% of production value for Atlantic Canada (Mustafa *et al.* 2001) to 7–10% in Scotland (Rae 2002). The present review indicates a cost of 6% of the value of the production for the countries affected by sea lice (Table 2). While this will vary for different farms and the same farms over time, it helps place the cost of lice in the context of other measures the industry may take to improve profitability.

References

Anon. (2003) *Salmon Farming: Towards an Integrated Pest Management Strategy for Sea Lice*. Report on the international conference on sea lice management, Aberdeen, Scotland, *Caligus* No.7, 6.

Bravo S. (2003) Sea lice in Chilean salmon farms. *Bulletin of the European Association of Fish Pathologists* **23,** 197–200.

Carvajal J., Gonzalez L. & Nascimento M. (1998) Native sea lice (Copepoda: Caligidae) infestation of salmonids reared in net-pen systems in southern Chile. *Aquaculture* **166,** 241–246.

Costello M.J. (1993) Review of methods to control sea lice (Caligidae: Crustacea) infestations on salmon (*Salmo salar*) farms. In: *Pathogens of Wild and Farmed Fish: Sea Lice* (ed. by G.A. Boxshall & D. Defaye), pp. 219–252. Ellis Horwood, Chichester.

Costello M.J. (2006) Ecology of sea lice parasitic on farmed and wild fish. *Trends in Parasitology* **22,** 475–483.

Costello M.J., Grant A., Davies I.M., Cecchini S., Papoutsoglou S., Quigley D. & Saroglia M. (2001) The control of chemicals used in aquaculture in Europe. *Journal of Applied Ichthyology* **17,** 173–180.

FAO Fisheries and Aquaculture Information and Statistics Service (2008) *Aquaculture Production 1950–2006. FISHSTAT Plus-Universal Software for Fishery Statistical Time Series [Online or CD-ROM]*. Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp (last accessed on 14 April 2008).

Ford J.S. & Myers R.A. (2008) A global assessment of salmon aquaculture impacts on wild salmonids. *PLoS Biology* **6,** e33, doi:10.1371/journal.pbio.0060033.

Hayward C.J., Aiken H.M. & Nowak B.F. (2008) An epizootic of *Caligus chiastos* on farmed southern bluefin tuna *Thunnus maccoyi* off South Australia. *Diseases of Aquatic Organisms* **79,** 57–63.

Maroni K., Steinshylla K. & Willumsen F.W. (1994) *Optimal lokalisering, strukturering og drift av matfiskanlegg*. Rapport 193, KPMG (Akva Instituttet), Trondheim. In Norwegian, p. 73. In: Hevrøy E.M. Boxaspen K., Oppedal F., Taranger G.L., Holm J.C. 2003. The effect of artificial light treatment and depth on the infestation of the sea louse *Lepeophtheirus salmonis* on Atlantic salmon (*Salmo salar* L.) culture. *Aquaculture* **220,** 1–14.

Michie I. (2001) Causes of downgrading in the salmon farming industry. Kestin, S.C. and Warris, P.D., editors *Farmed fish quality*. Fishing News Books, Oxford, pp. 129–136.

Mustafa A., Rankaduwa W. & Campbell P. (2001) Estimating the cost of sea lice to salmon aquaculture in eastern Canada. *Canadian Veterinary Journal* **42,** 54–56.

Nagasawa K. (2004) Sea lice, *Lepeophtheirus salmonis* and *Caligus orientalis* (Copepoda: Caligidae), of wild and farmed fish in sea and brackish waters of Japan and adjacent regions: a review. *Zoological Studies* **43,** 173–178.

Pike A.W. & Wadsworth S.L. (1999) Sea lice on salmonids: their biology and control. *Advances in Parasitology* **44,** 233–337.

Rae G.H. (2002) Sea louse control in Scotland, past and present. *Pest Management Science* **58,** 515–520.

Sinnott R. (1998) Sea lice – watch out for the hidden costs. *Fish Farmer* **21**(3)**,** 45–46.

Treasurer J.W. (2005) Cleaner fish: a natural approach to the control of sea lice on farmed fish. *Veterinary Bulletin* **75,** 17–29.

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