

## Sea lice removal by cleaner fish in salmon aquaculture: a review of the evidence base

Kathy Overton, Luke T. Barrett, Frode Oppedal, Tore S. Kristiansen, Tim Dempster\*

\*Corresponding author: dempster@unimelb.edu.au

*Aquaculture Environment Interactions* 12: 31–44 (2020)

**Table S1:** A summary of the current literature (scientific reports and peer-reviewed journal articles) on cleaner fish experiments testing efficacies at either tank ( $\leq 1 \text{ m}^3$ ), small (100-250  $\text{m}^3$  cages), small commercial (1000-15000  $\text{m}^3$  cages) or large commercial scale ( $>35000 \text{ m}^3$  cages). Degree of site exposure for each paper is categorised as either 1 (inner loch or fjord), 2 (sheltered by at least one body of land), or 3 (exposed coastal site). Effect sizes below were either the reported values or extracted from figures (GetData Graph Digitizer 2.26). Where multiple samples were taken following stocking of cleaner fish, the mean effect over the experimental period was used.

Experimental scale	Citation	Experiment period and temperature	Experimental unit size	Site exposure	Species, N, size, stocking density of cleaner fish	N salmon, size	Single cleaner fish species per cage?	N treatment replicates (per level)	N control replicates	Multiple study sites?	Key findings / notes	Effect size (% reduction); mean of post-stocking sampling dates
Tank scale	Tully et al. 1996	Unspecified period; 15°C	1000 L; 1 $\text{m}^3$	N/A	Rockcook wrasse (10 fish; 67% density)	15 fish; 200-400 g	Yes	1	1	N/A	Salmon were infested mostly by <i>Caligus elongatus</i> (93%) with some post-chalimus stages of <i>L. salmonis</i> . 96% of the total available lice in the rockcook tank were consumed.	96% all stages
					Goldsinny wrasse (10 fish; 67% density)						Goldsinny did not reduce lice levels, and no lice were recovered from stomachs.	0% all stages
	Leclercq et al. 2014	20 to 24 May 2013; 10 °C	600 L; ~1 $\text{m}^3$	N/A	Small cultured ballan wrasse (24 g) (3 tank <sup>-1</sup> ; 5% density)	60 fish; 145 g	Yes	3	3	N/A	All size classes of ballan wrasse reduced mobile lice loads within 84 hrs.	91% mobile lice
					Medium cultured ballan wrasse (44 g) (3 tank <sup>-1</sup> ; 5% density)							90% mobile lice
				Large (75 g) cultured ballan wrasse (3 tank <sup>-1</sup> ; 5% density)							96% mobile lice	
	Leclercq et al. 2014	26 to 28 May 2013; 12 °C	600 L; ~1 $\text{m}^3$	N/A	Ballan wrasse (2 tank <sup>-1</sup> ; 6% density)	34 fish; 141 g	Yes	2	2	N/A	Lice density was reduced regardless of the presence of supplementary feeding.	99% mobile lice
Small scale	Bjordal 1991	26 to 27 Oct 1987; unspecified temperature	5 x 5 x 4 m; 100 $\text{m}^3$	Unspecified	Mixed wrasse (24 rockcook, 2 goldsinny, 2 ballan, 1 cuckoo; total 73% density)	40 fish; 300 g	No	1	N/A	No	Lice density was reduced within 24 hrs.	57% adult lice

Bjordal 1991	17 Aug to 4 Nov 1988; unspecified temperature	5 x 5 x 4 m; 100 m <sup>3</sup>	Unspecified	Cuckoo wrasse (25 fish; 11% density)	220 fish; 84 g	Yes	1	2	No	Cuckoo wrasse had no effect for first few days of experiment, but were more effective after delousing treatment (for unknown reasons)	51% all stages (after delousing)
				Cuckoo wrasse (50 fish; 23% density)							62% all stages (after delousing)
				Goldsinny wrasse (25 fish; 11% density)							60% all stages
				Goldsinny wrasse (50 fish; 23% density)							62% all stages
				Rockcook wrasse (50 fish; 23% density)							69% all stages
				Mixed wrasse (15 goldsinny, 15 rockcook; total 14% density)							71% all stages
Treasurer 1994	28 Aug 1991 to 6 Jan 1992; 8-13 °C	5 x 5 x 4 m; 100 m <sup>3</sup>	1	Goldsinny wrasse (25 fish; 4% density)	625 fish; 150-250 g	Yes	1	1	No	Goldsinny significantly reduced lice numbers compared to control. The control cage was stocked with wrasse for 10 days to avoid chemotherapeutant treatment (decreased lice from 50 to 0.9 lice fish <sup>-1</sup> ), while no treatment was required in goldsinny cage.	77% mobile lice
Skiftesvik et al. 2013	Sept-Oct 2012; unspecified temperature	5.5 x 5.5 x 7 m; 212 m <sup>3</sup>	2	Cultured ballan wrasse sourced from IMR (25 fish; 5% density)	500 fish; 429 g	Yes	4	4	No	Reduction in lice evidence after 1 week. Pre-adult and adult lice levels remained low and stable in cleaner fish cages. 9 lice fish <sup>-1</sup> in control cages, <1 lice fish <sup>-1</sup> in cages stocked with wrasse.	80% mobile lice
				Cultured ballan wrasse sourced from Marine Harvest (25 fish; 5% density)							89% mobile lice
				Wild ballan wrasse (25 fish; 5% density)							68% mobile lice
				Mix of wild corkwing wrasse and cultured ballan wrasse (25 fish; 5% density)							91% mobile lice
Imsland et al. 2014a, 2014b, 2015	12 June to 5, 24 or 26 Aug 2012; 9-13 °C	5 x 5 x 5 m; 125 m <sup>3</sup>	2	Small cultured lumpfish (12 fish; 10% density)	120 fish; 619 g	Yes	2	2	No	Small lumpfish reduced lice infestation levels from day 25 onwards for both 10% and 15% stocking densities. At the end of the trial, the 10% and 15% stocked cages had 60% and 56% fewer lice than controls, respectively.	60% all stages
				Small cultured lumpfish (18 fish; 15% density)	120 fish; 619 g						56% all stages
				Large wild lumpfish (4 fish; 5% density)	80 fish; 2400 g						9% all stages
				Large wild lumpfish (8 fish; 10% density)	80 fish; 2400 g						15% all stages
										Large lumpfish reduced lice infestations compared to controls in the 5% (day 15) and 10% (day 15 and 43) stocking densities. Similar lice levels at the end of the experiment (day 57).	

	Imsland et al. 2016	25 Jan to 5 July 2015; 5-11 °C	5 x 5 x 5 m; 125 m <sup>3</sup>	2	Small lumpfish (22.6 ± 0.7 g) (15 fish; 10% density)	150 fish; 538 g	Yes	2	2	No	Lice consumption varied with lumpfish size.	36% all stages
					Medium lumpfish (77.4 ± 3.6 g) (15 fish; 10% density)							40% all stages
					Large lumpfish (113.5 ± 2.1 g) lumpfish (15 fish; 10% density)							30% all stages
	Skiftesvik et al. 2017	8 Dec 2015 to 9 Mar 2016; 7 °C	5 x 5 x 5 m; 125 m <sup>3</sup>	2	Cultured ballan wrasse (25 fish; 5% density)	500 fish; 130 g	Yes	3	3	No	Tested effect of artificial light on cleaner fish performance. Low efficacy overall for lice removal. Too few lice in ballan wrasse trial to estimate efficacy.	N/A
					Wild goldsinny wrasse (25 fish; 5% density)							18% preadult and adult female
					Cultured lumpfish (25 fish; 5% density)							10% preadult and adult female
	Skiftesvik et al. 2017	1 Nov 2016 to 12 Jan 2017; 9 °C	5 x 5 x 5 m; 125 m <sup>3</sup>	2	Wild goldsinny wrasse (30 fish; 10% density)	300 fish; 2922 g	Yes	3	3	No	Tested effect of artificial light on cleaner fish performance. Higher lice numbers in treatment cages compared to controls.	-14% preadult and adult female
					Wild corkwing wrasse (30 fish; 10% density)							-28% preadult and adult female
	Skiftesvik et al. 2018	3 to 30 Sept 2014; 16 °C	5 x 5 x 5 m; 125 m <sup>3</sup>	2	Goldsinny wrasse (24 fish; 4.7% density)	510 fish; 435 g	Yes	3	3	No	Recorded behavioural observations of cleaner fish stocked alone and in combination with other species in cages, as well as lice removal efficacy. Trial was cut short due to amoebic gill disease outbreak.	62% preadult and adult female
					Corkwing wrasse (24 fish; 4.7% density)							58% preadult and adult female
					Ballan wrasse (24 fish; 4.7% density)							49% preadult and adult female
					Lumpfish (24 fish; 4.7% density)							30% preadult and adult female
					Goldsinny and ballan wrasse (12 fish of each; 4.7% density)		72% preadult and adult female					
Goldsinny and corkwing wrasse (12 fish of each; 4.7% density)					50% preadult and adult female							
Goldsinny wrasse and lumpfish (12 fish of each; 4.7% density)					68% preadult and adult female							
Corkwing and ballan wrasse (12 fish of each; 4.7% density)					62% preadult and adult female							
Corkwing wrasse and lumpfish (12 fish of each; 4.7% density)					39% preadult and adult female							
Ballan wrasse and lumpfish (12 fish of each; 4.7% density)					49% preadult and adult female							
Small commercial scale	Tully et al. 1996	28 June 1992 to 18 Jan 1993; unspecified temperature	50-70 m circumference, 10 m depth; 2864 m <sup>3</sup>	2	Goldsinny wrasse (~166 fish cage <sup>-1</sup> ; ~1% density)	Treatment: 13000-24000 fish Control: 20000 fish	Yes	3	3	No	Cleaner fish did not reduce <i>C. elongatus</i> loads. Fish were treated with chemotherapeutants due to high lice levels in farms despite cleaner fish in cages. Trial abandoned after ~5 months.	-21% all stages
	Treasurer	June 2010 to	90 m	2	Mixture of unspecified	Not	No	Not	Not	No	Cleaner fish delayed treatments. Two	50% mobile lice

	2013	May 2011; unspecified temperature	circumference cage, unspecified depth; ~19742 m <sup>3</sup>		species (4% density)	specified		specified	specified		fewer medicinal treatments in cages with wrasse stocked. Wrasse were less effective in colder months.	
	Treasurer 2013	Sept 2012 to unspecified end date; unspecified temperature	24 x 24 x 10 m; 5760 m <sup>3</sup>	2	Farmed ballan wrasse (650) and wild unspecified wrasse (300); 2% density	54000 fish; 900 g	No	1	2	No	One sampling date (10 weeks after stocking). No lice present in wrasse pen, mean numbers of sea lice in control pens were higher (0.23-0.3).	<b>100% all stages</b>
<b>Large commercial scale</b>	Imsland et al. 2018	6 Oct 2015 to 17 May 2016; 4-8 °C	130 m circumference; 37688 m <sup>3</sup> volume	2	Lumpfish (8000 fish; 4% density)	193304 fish; 198 g	Yes	2	2	No	More pre-adult lice in cages without cleaner fish from February to March. Fewer adult female lice in cages with 6 and 8% densities of lumpfish (vs. controls). Between weeks 4-11, 60-100% less adult female lice in lumpfish groups compared to controls.	<b>63% preadult and adult female</b>
					Lumpfish (12000 fish; 6% density)							<b>54% preadult and adult female</b>
					Lumpfish (16000 fish; 8% density)							<b>73% preadult and adult female</b>