Appendix A

A model for parasite-mediated predation

Potential non-linear effects

The effect of parasites on predation susceptibility is likely non-linear; at some point the impact must plateau. A non-linear form of the attack rate in the Type II functional response can be derived from a mechanistic understanding of the attack process. First, there is a decision to attack, which occurs at rate γ_i. Once a prey item is targeted, it is successfully captured with some probability. It is likely that this probability increases with parasitism, e.g., Pr(captured|targeted) = $1 - \theta_i e^{-\delta_i p}$, where $1 - \theta_i$ is the probability of successful capture in the absence of parasites. However, we note that the linear approximation $\theta_i e^{-\delta_i p} \approx \omega_i p$ is valid for moderate louse abundances (Fig. A1A), such as the averages numbers of lice per fish found on wild juvenile salmon (Fig. 3C of the main text).

Empirical evidence of selective predation

Detailed experimental methods

Sample collection

We obtained four independent groups of coho salmon smolts, to be used as predators, by beach seine (dimensions 35 m × 3 m with 4 mm mesh). At the research facility (Fig. A2), coho smolts were housed in a large flow-through net pen (dimensions 6 m × 6 m × 2.9 m deep) and fed mixed schools of juvenile pink and chum salmon at a rate of ~2 prey per coho per day. We also obtained pink and chum salmon fry by beach seine,

and either sorted fry immediately for experiments or stored them in flow-through ocean

enclosures (dimensions 1.5 m × 1.5 m × 0.5 m deep). We fed pink and chum that were

held for more than 48 hours with EWOS salmon feed (micro #0-1; EWOS Canada,

Surrey, British Columbia, Canada) at a rate of ~1.5% body mass per day.

Experimental setup

Two days prior to an experiment, we haphazardly selected the required number of

coho predators from the holding pen, exchanging coho until the size distribution of

selected coho approximately matched that of the overall population in the holding pen.

We housed selected coho in flow-through ocean enclosures or net pens without food for

two days before trials began. Several hours before experiments, we transferred the food-

deprived coho to one side of divided experimental net pens (dimensions 3.2 m × 4.4 m ×

2.3 m deep).

Each experiment consisted of two simultaneous trials: one with clean prey, free of

any sea lice, and one with lousy prey that were infested with at least one sea louse each.

Prior to experiments, we inspected pink and chum fry in seawater-filled Ziploc® bags

(Krkošek et al. 2005) and sorted the fry into clean and lousy infestation categories. We

classified fry as clean if they had no visible sea lice of any stage or species and were free

of any apparent louse-induced morbidity (e.g., scars from attached louse stages). We

classified prey as lousy if they had a minimum of one sea louse (*L. salmonis*) of a

chalimus II stage (Hamre et al. 2013) or motile stage. Pink or chum that were only

infested with earlier stages of sea lice were not used in experiments, as early louse stages

are less pathogenic (Brauner et al. 2012), and would be expected to result in a smaller

effect size between clean and lousy prey that would be difficult to detect in experiments.

Lousy prey may have also been infested by *Caligus clemensi*, a generalist louse species, but the presence of *C. clemensi* only was not sufficient to classify prey as lousy. *Caligus* lice are not as pathogenic to juvenile salmon, and were observed to frequently move amongst hosts (Costello 2006), blurring the distinction between lousy and clean fry.

The same two people sorted prey for all experiments. Their ability to accurately perform sea louse identification and prey size matching was tested; see below.

Assessing experimenters' ability to accurately sort prey

We size-matched pink and chum within and between infestation categories to minimize the impact of prey size as a confounding factor (Hargreaves and LeBrasseur 1986). The same two individuals sorted pink and chum prey for all experiments. Their ability to accurately identify sea lice with the naked eye was tested by measuring and re-inspecting with a 16 × hand-lens a group of pink and chum salmon that were sorted with the naked eye. Inspecting salmon using a hand lens increased handling time of the prey prior to experiments, and we wanted to assess the trade-off between accuracy and handling time when sorting fry into infestation categories. With the naked eye, sorters correctly identified 86% of the sea lice found using a hand lens. Five out of 100 pink or chum salmon fry were miscategorised as clean when they were infested with one sea louse each. We found these error rates acceptable, but decided to use hand lenses for sorting fry in 2014, as the handling time was reduced with practice.

We also tested the experimenters' ability to size-match fry. A random subsample of collected fry indicated that prior to size-matching, chum salmon were significantly larger than pink salmon (t-test, $t = 2.75$, df $= 97$, $p = 0.007$), but not so after size matching ($t = -0.029$, df $= 98$, $p = 0.977$).

TABLE A1. Collection dates and locations for coho salmon smolts used as predators in experiments. Fork lengths were measured at the end of their time in captivity.

Collection date	Location	Coordinates	n	Fork length (mm)	
				mean	95% CI[†]
Apr. 23, 2013	Kingcome Inlet	50º 54.682' N 126º 30.229' W	137	115.28	(112.45, 118.10)
May 9, 2013	Bond Sound	50º51.197' N 126º11.522'W	133	119.92	(117.92, 121.88)
Apr. 21, 2014	Kingcome Inlet	50º55.533' N 126º29.034'W	140	123.25	(120.82, 125.60)
May 9, 2014	Bond Sound	50º50.952' N 126º11.394'W	114	121.58	(119.59, 123.56)

† 95% confidence interval on the mean from 10 000 bootstrapped samples.

Supplemental Results

Coho predators consumed a total of 1475 out of 3674 pink and chum fry involved. The average fork length for pink salmon prey was 53.64 (53.28, 53.99) mm (mean and bootstrapped 95% CI), slightly larger than the average for chum salmon of 52.4 (52.11, 52.69) mm. This difference was also present in the control experiments, suggesting it was not just the result of selective predation on small pink prey. If anything, this size difference may have biased predation towards smaller, chum salmon (Hargreaves and LeBrasseur 1986).

The trials varied in the number of coho predators, number of prey and their length. This was due to limitations in the number of infested prey (described in main text). However, none of these variables was related to variations in prey preference among trials (Fig. A3). When these variables were included in the mixed-effects model for logit(α), none of them improved the fit of the model (Table A2).

TABLE A2. Parameter estimate from a linear mixed-effects model for logit-transformed preference, including the additional factors not described in the main text: number of coho, number of prey at the beginning of the trial, and the length of the trial in hours.

		95% CI	
	Estimate	lower	upper
(Intercept)	0.045	-0.942	1.032
Lousy trials	0.167	-0.057	0.391
Number of coho	0.049	-0.034	0.132
Number of prey	-0.008	-0.057	0.041
Length of trial	0.001	-0.049	0.052

Control experiments

The eight control trials without coho salmon predators had no substantial mortality of pink and chum salmon. In three of the eight control trials (experiments 11, 19 and 22; online supplement), we recovered one more chum salmon than started in the trial. In two of these trials, there may have been a misidentification of a chum salmon as pink going into the trial, while the third was likely due to human error in counting fish into the net pen. In control experiment 19, we had a total of three mortalities in each trial out of 40 fry in each trial, while all other control trials had one or zero mortalities. Field records show poor condition of the fish upon capture and rough weather may have contributed to the anomalously high mortality for this one control experiment. Even considering this control experiment, the number of potential non-predator mortality and counting errors was small enough that these are unlikely to have influenced the overall results.

In the main text, we reported that the mean number of lice per prey declined during predation experiments, suggesting that lousy fish were selectively preyed upon (Table 1 and Fig. 2B). This decline in lice was observed for both attached and mobile louse stages suggesting that it was not just due to mobile lice jumping off hosts. Furthermore, we did not observe a decline in lice on prey in control experiments. The

same GLMM described in the main text for the number of lice per fish was fit to the

control data, and suggested that the mean number of lice per fish was not different on

pink and chum salmon, and not different before and after experiments (Table A3).

TABLE A3. The mean number of lice per fish before and after control experiments[†].

Prey species	Before	After
Pink	1.165 (1.047, 1.297)	1.167 (1.049, 1.298)
Chum	1.168 (1.050, 1.300)	1.170 (1.051, 1.301)

† Estimates are the model-averaged predictions from Poisson GLMMs with prey species and before/after as fixed effects (full model) and experiment number as a random effect.

Mean number of lice per wild juvenile salmon (Fig. 3A)

We estimated the mean number of sea lice per wild juvenile salmon from

monitoring data from Peacock et al. (2013). Data were collected from 2001 to 2010,

although in 2001 only pink salmon were examined. Because we were interested in

comparing infestation levels between pink and chum salmon, we therefore excluded the

2001 data from the figure. Details of data collection and analysis are in Peacock et al.

(2013). Briefly, the mean number of lice per fish was estimated using a generalized

linear mixed-effects model, assuming a negative binomial distribution of lice per fish.

Fixed effects were year, host species (pink or chum) and the interaction between year and

host species allowing for different estimates for pink and chum each year. Random

effects included year, location, and sampling event. The model was fit using the AD

model builder package for R (Skaug et al. 2012, Fournier et al. 2012).

We also used the monitoring data to compare the numbers of sea lice of all stages

to those of just chalimus II and motile stages. Out experiments considered only chalimus

II and motile stage lice in the lousy experiments, but population-level studies have used

the mean number of lice of all stages when estimating the effect of sea lice on wild

salmon population survival from spawner-recruit data (Peacock et al. 2013, 2014). In

infestation years (e.g., 2002, 2004), there were proportionally more early-stage sea lice

on juvenile salmon (Fig. A6). This means that the range of sea louse abundances

considered in our experiments may not have been so different from the numbers of motile

and chalimus II lice on juvenile salmon in infestation years.

TABLE A4. Summary of observed captures from the one-hour observation period at the start of experiments in 2014.

Expt	Net pen	Coho	Successful captures[†]	$\overline{\gamma}$ [‡] (day^{-1})
14	A	10	2	4.8
15	A	20	20	24.0
16	A	20	17	20.4
17	A	20	9	10.8
18	A	10	9	21.6
20	A	15	14	22.4
21	B	20	10	12.0
23	B	20	11	13.2
24	B	20	15	18.0
25	B	20	17	20.4
26	B	10	8	19.2
27	B	10	2	4.8
				16.0

†Successful captures are those that did not escape and resulted in consumption of the prey item.
‡ γ was calculated as the number of successful captures in one hour × 24 hours per day / the number of coho.

LITERATURE CITED

Brauner, C.J., Sackville, M., Gallagher, Z., Tang, S., Nendick, L., and Farrell, a P. 2012. Physiological consequences of the salmon louse (*Lepeophtheirus salmonis*) on juvenile pink salmon (*Oncorhynchus gorbuscha*): implications for wild salmon ecology and management, and for salmon aquaculture. Philos. Trans. R. Soc. Lond. B. Biol. Sci. **367**: 1770–9. doi: 10.1098/rstb.2011.0423.

Costello, M.J. 2006. Ecology of sea lice parasitic on farmed and wild fish. Trends Parasitol. **22**: 475–483.

Fournier, D. a., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A., and Sibert, J. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. **27**: 233–249. doi: 10.1080/10556788.2011.597854.

Hamre, L.A., Eichner, C., Caipang, C.M.A., Dalvin, S.T., Bron, J.E., Nilsen, F., Boxshall, G., and Skern-Mauritzen, R. 2013. The Salmon Louse Lepeophtheirus salmonis (Copepoda: Caligidae) Life Cycle Has Only Two Chalimus Stages. PLoS One **8**: e73539. Public Library of Science. doi: 10.1371/journal.pone.0073539.

Hargreaves, N.B., and LeBrasseur, R.J. 1986. Size selectivity of coho (*Oncorhynchus kisutch*) preying on juvenile chum salmon (*O. keta*). Can. J. Fish. Aquat. Sci. **43**: 581–586. doi: 10.1139/f86-069.

Krkošek, M., Morton, A., and Volpe, J.P. 2005. Nonlethal assessment of juvenile pink and chum salmon for parasitic sea lice Infections and fish health. Trans. Am. Fish. Soc. **134**: 711–716. doi: 10.1577/T04-133.1.

Peacock, S.J., Connors, B.M., Krkošek, M., Irvine, J.R., and Lewis, M.A. 2014. Can reduced predation offset negative effects of sea louse parasites on chum salmon? Proc. R. Soc. B Biol. Sci. **281**: 20132913. doi: 10.1098/rspb.2013.2913.

Peacock, S.J., Krkošek, M., Proboszcz, S., Orr, C., and Lewis, M.A. 2013. Cessation of a salmon decline with control of parasites. Ecol. Appl. **23**: 606–620. doi: 10.1890/12-0519.1.

Skaug, H., Fournier, D., Nielsen, A., Magnusson, A., and Bolker, B. 2012. glmmADMB: Generalized Linear Mixed Models Using AD Model Builder. Available from http://r-forge.r-project.org/projects/glmmadmb/.
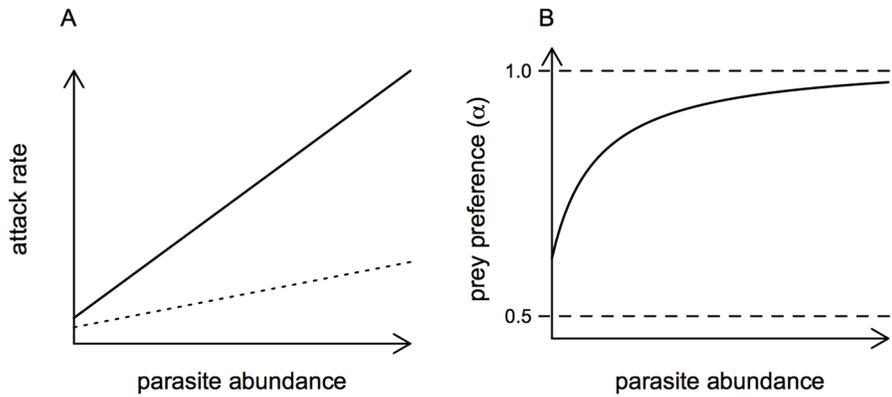
A

B

FIG. A1. (A) The parasite-mediated attack rate on pink salmon (solid line), the preferred prey, and chum salmon (dotted line), a less-desirable prey species, increases linearly with the number of parasites. (B) A higher per-parasite increase in predation on the preferred prey species (solid line in A means that predator preference for that species will increase as prey become more heavily parasitized.
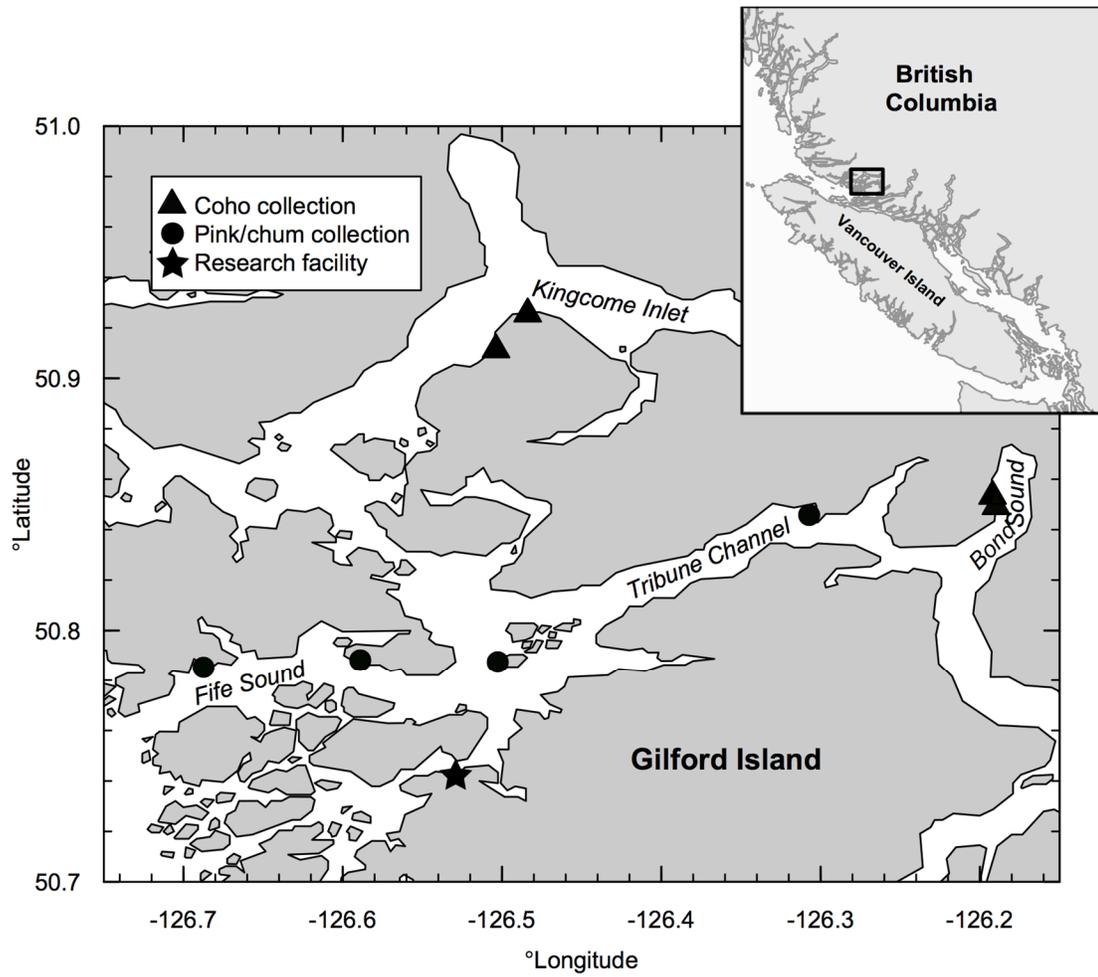
FIG. A2. The Broughton Archipelago on the west coast of Canada, showing the locations of coho salmon collections (triangles), pink and chum salmon collections (circles) and the floating research facility where we conducted experiments (star).
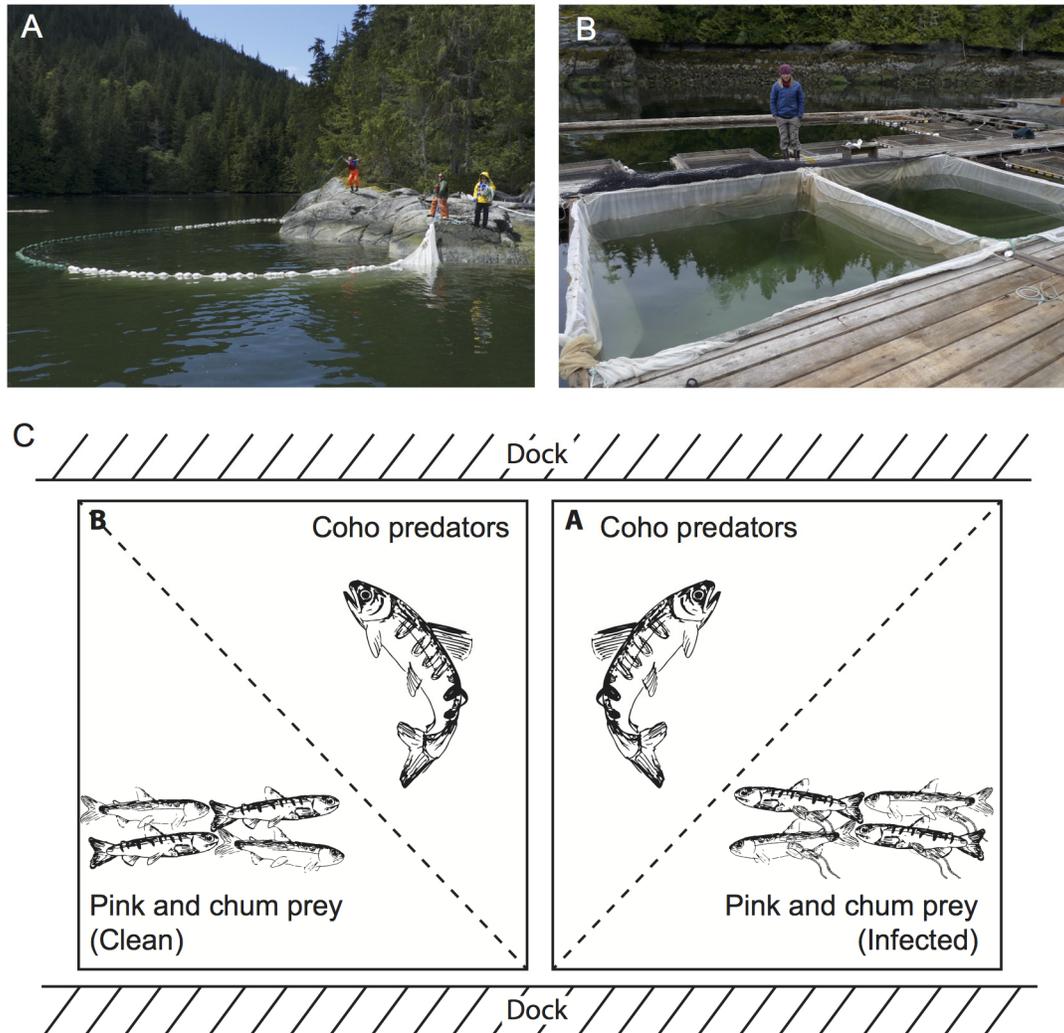
FIG. A3. (A) Collecting pink and chum prey by beach seine in the Broughton Archipelago. (B) Experimental net pens with divider down, allowing predators access to prey. (C) Diagram of the experimental net pens, showing dividers on the diagonal (dashed lines).
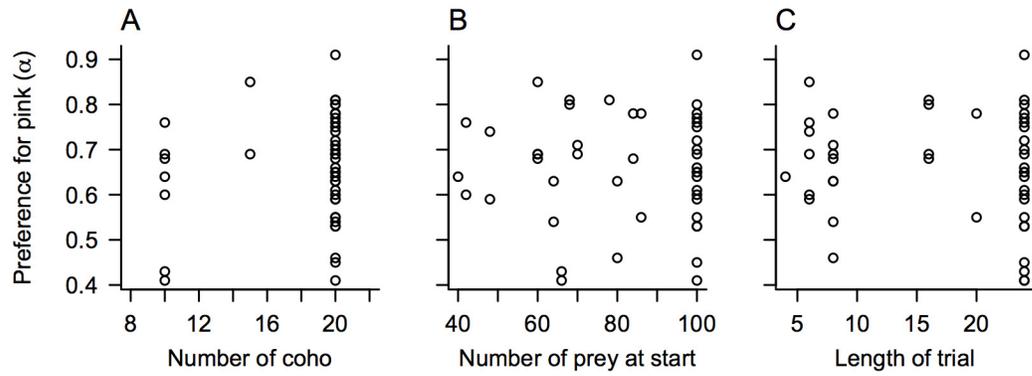
FIG. A4. The preference for pink salmon (α) over (A) the number of coho predators in the trial, (B) the total number of prey at the start of the trial, and (C) the length of the trial (hours).
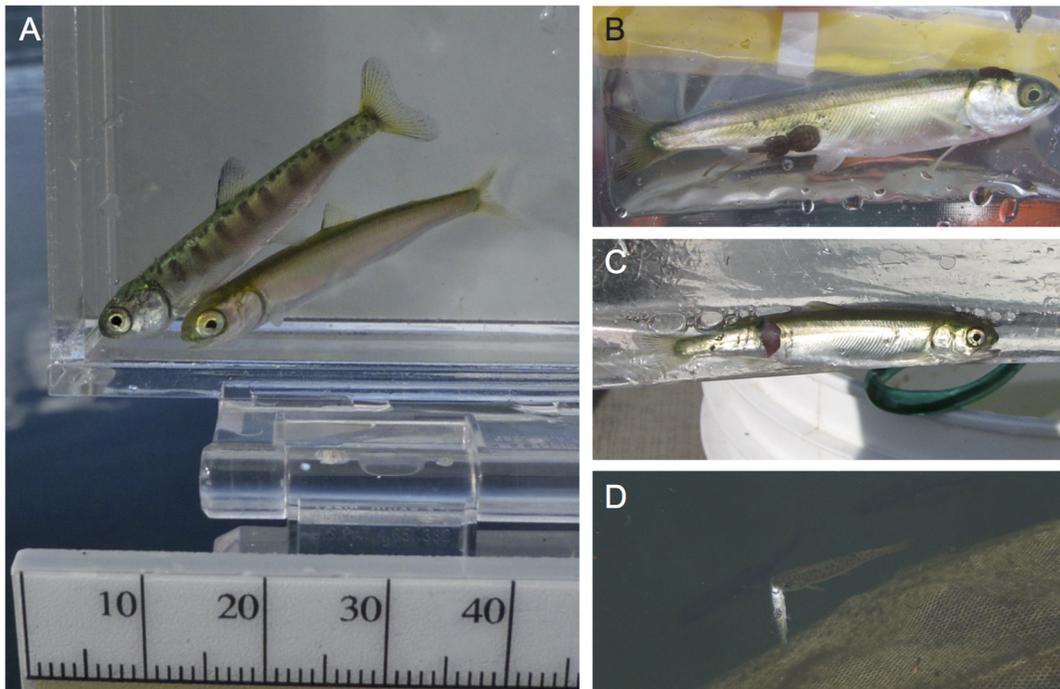

FIG. A5. (A) Juvenile pink and chum salmon, used as prey in experiments. The scale bar at the bottom is in mm. (B) Pink salmon fry with scars from the motile sea louse on its

flank. (C) A predation scar on the caudal peduncle of a juvenile pink salmon, showing the

characteristic semi-circular tooth mark from a coho salmon. (D) A coho smolt with a
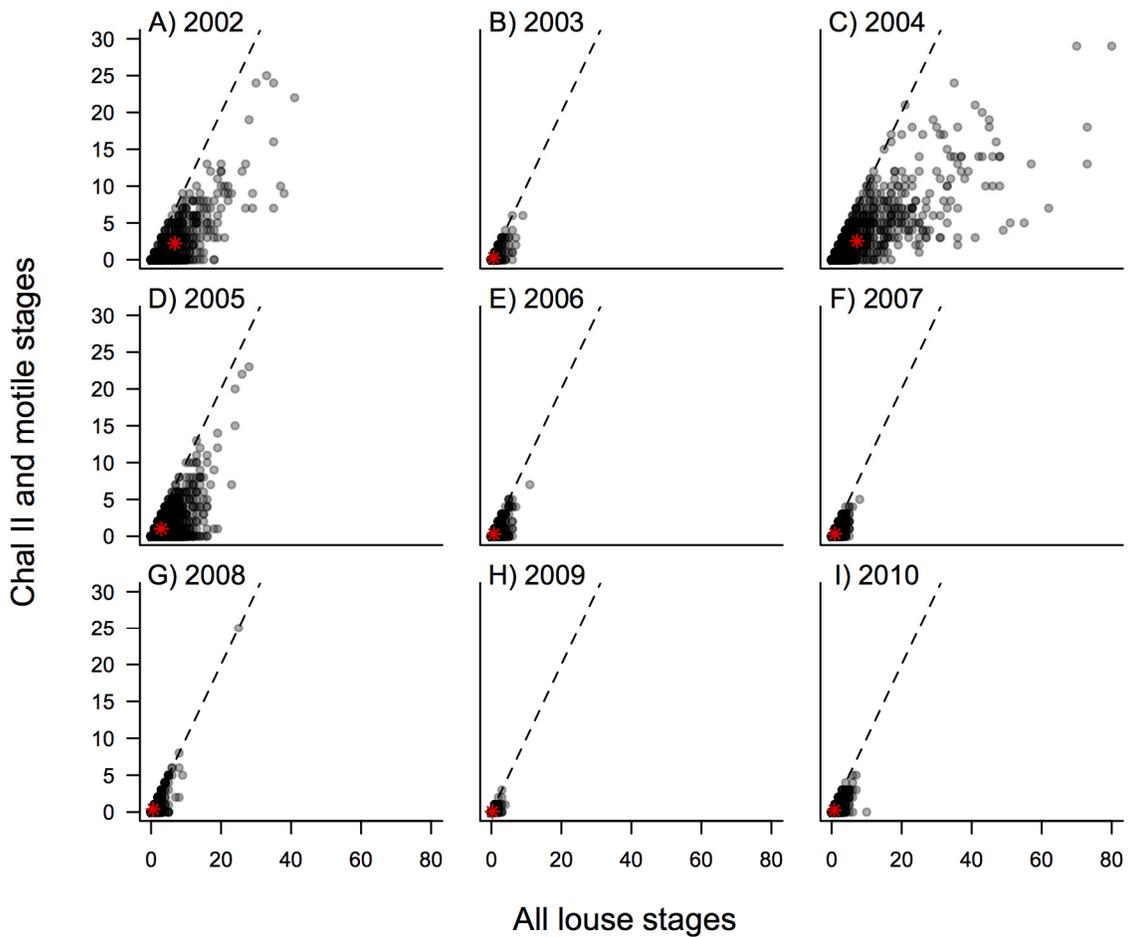
juvenile chum salmon in its jaws.

FIG. A6. The number of sea lice of all stages, plotted against the number of sea lice of

chalimus II and motile stages only, from juvenile salmon monitoring from 2002-2010

(Peacock et al. 2013). In each panel, the dashed line is the 1:1 line, and the red star is the

mean of all louse stages plotted against the mean of just chalimus II and motile stages.