AJAE appendix for

# "Matching property rights and transboundary ecological processes: The case of Norwegian salmon aquaculture"

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October 9, 2025

Note: The material contained herein is supplementary to the article named in the title and published in the American Journal of Agricultural Economics.

## Summary Statistics

*Table A1: Summary Statistics for Salmon Production Farms with Production Cycles Started Between 2012 and 2017.*

| Variable | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| Harvest (ton) | 200.79 | 461.61 | 0.00 | 5438.51 |
| Biomass (ton) | 1289.30 | 1174.20 | 0.00 | 10538.47 |
| Feed (ton) | 242.09 | 220.65 | 0.00 | 3564.93 |
| Salmon lice per ten fish | 12.86 | 22.71 | 0.00 | 881.00 |
| Local biomass density | 0.14 | 0.04 | 0.00 | 0.40 |
| Number of cycles | 56.26 | 29.38 | 1.00 | 112.00 |
| Minimun distance to an active farm | 4.86 | 4.34 | 0.25 | 99.00 |
| BHHI | 0.21 | 0.10 | 0.10 | 1.00 |
| Chemical bath | 0.19 | 0.50 | 0.00 | 5.00 |
| Chemical feed | 0.09 | 0.42 | 0.00 | 5.00 |
| Fallowing frequency | 0.46 | 1.19 | 0.00 | 5.00 |
| cleaner fish monthly flow (x1000) | 2.54 | 10.79 | 0.00 | 374.02 |
| Time at sea | 9.21 | 5.55 | 1.00 | 23.00 |
| sea temperature (°C) | 9.67 | 3.51 | 2.60 | 21.60 |

Note: The number of production sites is 849, 12 production areas, 81 different firms, 1914 production cycles.

*Table A2: Proportion of Production Cycles with Positive Salmon Lice by Month and Production Zone.*

| Production zone | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 91% | 90% | 86% | 71% | 78% | 82% | 79% | 76% | 75% | 79% | 87% | 89% |
| 3 | 94% | 94% | 89% | 80% | 89% | 89% | 91% | 87% | 80% | 92% | 93% | 94% |
| 4 | 96% | 91% | 89% | 76% | 82% | 79% | 84% | 79% | 78% | 88% | 92% | 91% |
| 5 | 88% | 90% | 90% | 83% | 83% | 88% | 94% | 94% | 90% | 90% | 88% | 81% |
| 6 | 91% | 90% | 82% | 75% | 81% | 84% | 90% | 89% | 86% | 87% | 84% | 85% |
| 7 | 93% | 90% | 84% | 69% | 74% | 76% | 83% | 82% | 81% | 85% | 86% | 83% |
| 8 | 84% | 81% | 78% | 66% | 54% | 74% | 86% | 88% | 85% | 87% | 85% | 81% |
| 9 | 77% | 72% | 67% | 64% | 51% | 52% | 75% | 82% | 87% | 88% | 87% | 80% |
| 10 | 70% | 72% | 61% | 54% | 48% | 49% | 67% | 84% | 88% | 85% | 75% | 72% |
| 11 | 55% | 52% | 62% | 40% | 48% | 42% | 58% | 75% | 73% | 83% | 75% | 57% |
| 12 | 56% | 69% | 59% | 60% | 46% | 35% | 55% | 84% | 84% | 79% | 80% | 62% |

## Full Tables and Additional Estimations

*Table A3: Full table. Impact of Ownership Concentration on the Probability of Initial Salmon Lice Occurrence (Extensive Margin).*

| Variable | Estimate | Std. Error | Boot. Std. Error | L. Boot. CI | U. Boot. CI |
|---|---|---|---|---|---|
| Local biomass density | 0.884 | 0.326 | 0.869 | -0.792 | 2.710 |
| Log sea temperature | -0.113 | 0.070 | 0.084 | -0.285 | 0.038 |
| Log sea temperature (Lag=1) | 0.549 | 0.070 | 0.084 | 0.433 | 0.760 |
| Minimun distance to an active farm | -0.053 | 0.005 | 0.012 | -0.082 | -0.033 |
| BHHI | 0.089 | 3.456 | 5.877 | -9.816 | 12.582 |
| BHHI residuals | -3.009 | 3.518 | 5.960 | -14.689 | 8.769 |

Note: Estimates are asymptotically bias-corrected for binary choice models with fixed effects, as derived by Fernández-Val (2009). Bootstrapped standard errors (500 repetitions) are used to account for the two-stage estimation process. L and U denote the lower and upper confidence interval bounds. Bootstrapped 95% confidence intervals are reported.

*Table A4: Full results for the First Stage Estimates of the Effect of Ownership Concentration of Production Sites (BHHI) on Log Salmon Lice Levels (Intensive Margin).*

| Dependent Variable: | BHHI | | | |
|---|---|---|---|---|
| Model: | (1) | (2) | (3) | (4) |
| Variables | | | | |
| $Z_{pt}$ | -2.15*** | -2.15*** | -1.23*** | -1.22*** |
| | (0.172) | (0.172) | (0.142) | (0.141) |
| Log sea temperature | -0.0006 | -0.0006 | 0.002** | 0.002** |
| | (0.0007) | (0.0007) | (0.0008) | (0.0008) |
| Log sea temperature (Lag=1) | 0.002** | 0.002** | $-6.92 \times 10^{-5}$ | $-6.7 \times 10^{-5}$ |
| | (0.0008) | (0.0008) | (0.0008) | (0.0008) |
| Local biomass density | 0.008 | 0.008 | -0.0004 | -0.0003 |
| | (0.008) | (0.008) | (0.008) | (0.008) |
| Minimum distance to an active farm | 0.0001 | 0.0001 | 0.0002** | 0.0002** |
| | $(8.56 \times 10^{-5})$ | $(8.55 \times 10^{-5})$ | $(9.17 \times 10^{-5})$ | $(9.16 \times 10^{-5})$ |
| Time at sea | | $-9.59 \times 10^{-5}$ | | $1.8 \times 10^{-5}$ |
| | | $(8.6 \times 10^{-5})$ | | $(8.75 \times 10^{-5})$ |
| Chemical feed | | -0.0007** | | -0.0007** |
| | | (0.0003) | | (0.0003) |
| Fixed-effects | | | | |
| Year-by-quarter | Yes | Yes | | |
| Cycle-by-firm | Yes | Yes | | |
| Year | | | Yes | Yes |
| Quarter | | | Yes | Yes |
| Cycle | | | Yes | Yes |
| Fit statistics | | | | |
| Observations | 24,580 | 24,580 | 24,580 | 24,580 |
| Wald (IV only) | 155.70 | 155.47 | 75.011 | 74.923 |
| F-test (IV only) | 807.90 | 802.83 | 434.77 | 431.19 |

Note: The instrument, $Z_{pt}$, is the log inverse of the number of production cycles in other production zones. All models include controls for sea temperature, lagged sea temperature, local biomass density, and minimum distance to an active farm. Models 2 and 4 additionally control for time at sea and chemical feed. Driscoll-Kraay (L=6) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

*Table A5: Full results for the second Stage Estimates of the Effect of Ownership Concentration of Production Sites (BHHI) on Log Salmon Lice Levels (Intensive Margin).*

| Dependent Variable: | log(salmon lice per ten fish) | | | |
|---|---|---|---|---|
| Model: | (1) | (2) | (3) | (4) |
| Variables | | | | |
| BHHI | -16.6*** | -18.0*** | -11.8** | -12.9** |
| | (3.77) | (3.81) | (5.05) | (5.11) |
| Log sea temperature | -0.362*** | -0.368*** | -0.421*** | -0.423*** |
| | (0.052) | (0.052) | (0.052) | (0.052) |
| Log sea temperature (Lag=1) | 0.585*** | 0.594*** | 0.744*** | 0.749*** |
| | (0.058) | (0.058) | (0.057) | (0.057) |
| Local biomass density | 0.378 | 0.283 | 0.180 | 0.071 |
| | (0.361) | (0.362) | (0.337) | (0.337) |
| Minimum distance to an active farm | -0.010* | -0.009 | -0.011** | -0.009* |
| | (0.005) | (0.005) | (0.005) | (0.006) |
| Time at sea | | 0.110*** | | 0.109*** |
| | | (0.006) | | (0.006) |
| Chemical feed | | 0.152*** | | 0.169*** |
| | | (0.015) | | (0.015) |
| Fixed-effects | | | | |
| Year-by-quarter | Yes | Yes | | |
| Cycle-by-firm | Yes | Yes | | |
| Year | | | Yes | Yes |
| Quarter | | | Yes | Yes |
| Cycle | | | Yes | Yes |
| Fit statistics | | | | |
| Observations | 24,580 | 24,580 | 24,580 | 24,580 |
| Wu-Hausman | 52.123 | 63.406 | 13.909 | 17.319 |
| Wald (IV only) | 19.340 | 22.419 | 5.4254 | 6.4071 |
| F-test (IV only) | 58.841 | 70.440 | 16.314 | 19.878 |
| Kleibergen-Paap | 155.70 | 155.47 | 75.008 | 74.920 |

Note: The instrument, $Z_{pt}$, is the log inverse of the number of production cycles in other production zones. All models include controls for sea temperature, lagged sea temperature, local biomass density, and minimum distance to an active farm. Models 2 and 4 additionally control for time at sea and chemical feed. Driscoll-Kraay (L=6) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

*Table A6: Full Results for the First Stage Estimates of the Effect of Ownership Concentration of Production Sites (BHHI) on Salmon Lice per Ten Fish Using the Full Sample.*

| Dependent Variable: | BHHI | | | |
|---|---|---|---|---|
| Model: | (1) | (2) | (3) | (4) |
| Variables | | | | |
| $Z_{pt}$ | -2.15*** | -2.15*** | -1.26*** | -1.26*** |
| | (0.175) | (0.175) | (0.135) | (0.135) |
| Log sea temperature | -0.0004 | -0.0004 | 0.002*** | 0.002*** |
| | (0.0007) | (0.0007) | (0.0008) | (0.0008) |
| Log sea temperature (Lag=1) | 0.002** | 0.002** | -0.0007 | -0.0006 |
| | (0.0007) | (0.0007) | (0.0006) | (0.0006) |
| Local biomass density | 0.006 | 0.006 | -0.002 | -0.002 |
| | (0.008) | (0.008) | (0.008) | (0.008) |
| Minimum distance to an active farm | 0.0001 | 0.0001 | 0.0002*** | 0.0002*** |
| | $(7.03 \times 10^{-5})$ | $(7.03 \times 10^{-5})$ | $(7.95 \times 10^{-5})$ | $(7.96 \times 10^{-5})$ |
| Time at sea | | $-9.25 \times 10^{-5}$ | | $-4.34 \times 10^{-5}$ |
| | | $(7.94 \times 10^{-5})$ | | $(8.04 \times 10^{-5})$ |
| Chemical feed | | -0.0007** | | -0.0007** |
| | | (0.0003) | | (0.0003) |
| Fixed-effects | | | | |
| Year-by-quarter | Yes | Yes | | |
| Cycle-by-firm | Yes | Yes | | |
| Year | | | Yes | Yes |
| Quarter | | | Yes | Yes |
| Cycle | | | Yes | Yes |
| Fit statistics | | | | |
| Observations | 30,125 | 30,125 | 30,125 | 30,125 |
| Wald (IV only) | 150.62 | 150.88 | 87.313 | 87.542 |
| F-test (IV only) | 1,020.5 | 1,017.5 | 565.46 | 563.89 |

Driscoll-Kraay (L=6) standard-errors in parentheses
Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

*Table A7: Full Results for the Second Stage Estimates of the Effect of Ownership Concentration of Production Sites (BHHI) on Salmon Lice per Ten Fish Using the Full Sample.*

| Dependent Variable: | Salmon lice per ten fish | | | |
|---|---|---|---|---|
| Model: | (1) | (2) | (3) | (4) |
| Variables | | | | |
| BHHI | -5.8 | -6.5 | -14.3** | -14.7** |
| | (53.4) | (3.66) | (6.10) | (6.11) |
| Log sea temperature | -1.54* | -1.67*** | -2.03** | -2.11** |
| | (0.824) | (0.832) | (0.857) | (0.863) |
| Log sea temperature (Lag=1) | 7.59*** | 7.53*** | 8.40*** | 8.33*** |
| | (0.975) | (0.975) | (0.961) | (0.963) |
| Local biomass density | 3.32 | 2.65 | 4.47 | 3.74 |
| | (5.73) | (5.73) | (6.02) | (6.02) |
| Minimum distance to an active farm | -0.180*** | -0.171*** | -0.143*** | -0.135*** |
| | (0.058) | (0.058) | (0.062) | (0.062) |
| Time at sea | | 0.817*** | | 0.813*** |
| | | (0.107) | | (0.106) |
| Chemical feed | | 0.942*** | | 0.932*** |
| | | (0.264) | | (0.273) |
| Fixed-effects | | | | |
| Year-by-quarter | Yes | Yes | | |
| Cycle-by-firm | Yes | Yes | | |
| Year | | | Yes | Yes |
| Quarter | | | Yes | Yes |
| Cycle | | | Yes | Yes |
| Fit statistics | | | | |
| Observations | 30,125 | 30,125 | 30,125 | 30,125 |
| Wu-Hausman | 3.2625 | 4.0662 | 10.937 | 11.668 |
| Wald (IV only) | 2.0252 | 2.4922 | 5.4958 | 5.8144 |
| F-test (IV only) | 3.5823 | 4.3906 | 12.632 | 13.369 |
| Kleibergen-Paap | 150.61 | 150.88 | 87.31 | 87.539 |

Note: Coefficients on BHHI have been transformed into partial elasticities by dividing each 2SLS estimate of the BHHI effect by the sample mean of salmon lice levels ($\bar{y}$ = 13.03) lice per ten fish). This yields the approximate percent change in salmon lice associated with a 0.01-point increase in BHHI, facilitating comparison with the log-linear specifications reported in the main text. Driscoll-Kraay (L=6) standard-errors in parentheses. Signif. Codes: ***: 0.01, **: 0.05, *: 0.1

## Robustness of Standard Error Specifications

The main analysis in Table 3 uses Driscoll-Kraay standard errors, which are robust to general forms of cross-sectional and temporal dependence. In this appendix, we explore the robustness of our findings to two alternative, theoretically important specifications for the variance-covariance matrix.

### Conley spatial standard errors

First, we address the spatial nature of our data by using Conley (1999) standard errors, which assume that the correlation between two units is a function of the geographic distance between them. Guided by the biological literature establishing that a farm's infection pressure can extend up to 30km (Krkošek, Lewis, and Volpe 2005; Aldrin et al. 2013), we specify a 30km distance cutoff. Table A7 presents the results for our two preferred models using this specification.

The findings remain consistent with our main analysis. The coefficient on BHHI is large, negative, and statistically significant at the 5% level in models 1 and 2. This indicates that our results are robust to a more structured assumption about the spatial correlation based on the underlying biology of salmon lice dispersal.

*Table A8: Second Stage Estimates of the Effect of Ownership Concentration of Production Sites (BHHI) on the Log of Salmon Lice per Ten Fish (Intensive Margin).*

| Dependent Variable: | Log of salmon lice per ten fish | | | |
|---|---|---|---|---|
| Model: | (1) | (2) | (3) | (4) |
| Variables | | | | |
| BHHI | -16.6** | -18.0** | -16.6 | -18.0 |
| | (7.85) | (8.01) | (0.15) | (0.12) |
| Fixed-effects | | | | |
| Year-by-quarter | Yes | Yes | Yes | Yes |
| Cycle-by-firm | Yes | Yes | Yes | Yes |
| Fit statistics | | | | |
| Observations | 24,580 | 24,580 | | |
| Wu-Hausman | 52.123 | 63.406 | | |
| Wald (IV only) | 4.4628 | 5.0699 | | |
| F-test (IV only) | 58.841 | 70.440 | | |
| Kleibergen-Paap | 22.574 | 22.504 | | |

Notes: Second-stage estimates from the 2SLS model corresponding to Models 1 and 2. Conley (1999) standard errors with a 30km distance cutoff are reported in parentheses. Models 3 and 4 reports results from the wild cluster bootstrap (fwildclusterboot package in R) with 5,000 replications, clustered by production zone (N=11). The Webb weights distribution was used. The point estimate is for the effect of BHHI on log(y).

Significance codes: *p<0.1; **p<0.05; ***p<0.01.

## Wild cluster bootstrap by production zone

Second, we address the challenge of inference with a small number of clusters. Our analysis includes only 11 production zones, a context in which standard cluster-robust standard errors can be unreliable and lead to over-rejection of the null hypothesis. To address this, we use the wild cluster bootstrap (Cameron, Gelbach, and Miller 2008; Fischer and Roodman 2021), which is the standard for reliable inference in "few clusters" settings. We cluster at the production zone level with 5,000 replications, clustered by production zone (N=11). The Webb weights distribution was used (Webb, 2023).

Table A8 presents the results from this procedure. When using the wild cluster bootstrap, the p-values increase substantially, and the effect is no longer statistically significant at conventional levels. This result suggests that if one imposes the strict assumption that all correlation is contained within production zones and that zones are completely independent, the model lacks the statistical power to precisely estimate the effect. Given the potential for cross-zone ecological or economic spillovers, we maintain that the Driscoll-Kraay and Conley specifications, which allow for such dependence, are the most appropriate for this research context.