APPENDIX B. SUPPLEMENTARY INFORMATION FOR RESULTS

Table B.1. ANOVA tables for Models 1-5.

Model 1: Per-area nutrient removal			
Term	**df**	**F**	**P**
Cultured taxon	3	0.96	0.3
Mechanism	1	9.2	<0.0001
Culturing method	1	0.25	0.33
Cultured taxon x Mechanism	2	0.3	0.55
Residuals	59		

Model 2: Per-production nutrient removal			
Term	**df**	**F**	**P**
Cultured taxon	3	16	<0.0001
Mechanism	1	28	<0.0001
Culturing method	1	0.003	0.95
Residuals	73		

Model 3: Relative abundance (lnRR) effects at species level			
Term	**df**	**F**	**P**
Cultured taxon	2	2.9	0.58
Culturing method	2	2	0.14
Reference habitat structure	1	7.6	0.006
Cultured taxon x Culturing method	1	1.4	0.23
Residuals	161		

Model 4: Fish production at assemblage level (additional commercial value)			
Term	**df**	**F**	**P**
Cultured taxon	2	1.6	0.24
Culturing method	2	2.2	0.14
Reference habitat structure	1	2.1	0.16
Residuals	18		

Model 5: Fish production at assemblage level (additional recreational value)			
Term	**df**	**F**	**P**
Cultured taxon	2	0.53	0.6
Culturing method	2	1.1	0.4
Reference habitat structure	1	0.02	0.9
Residuals	18		

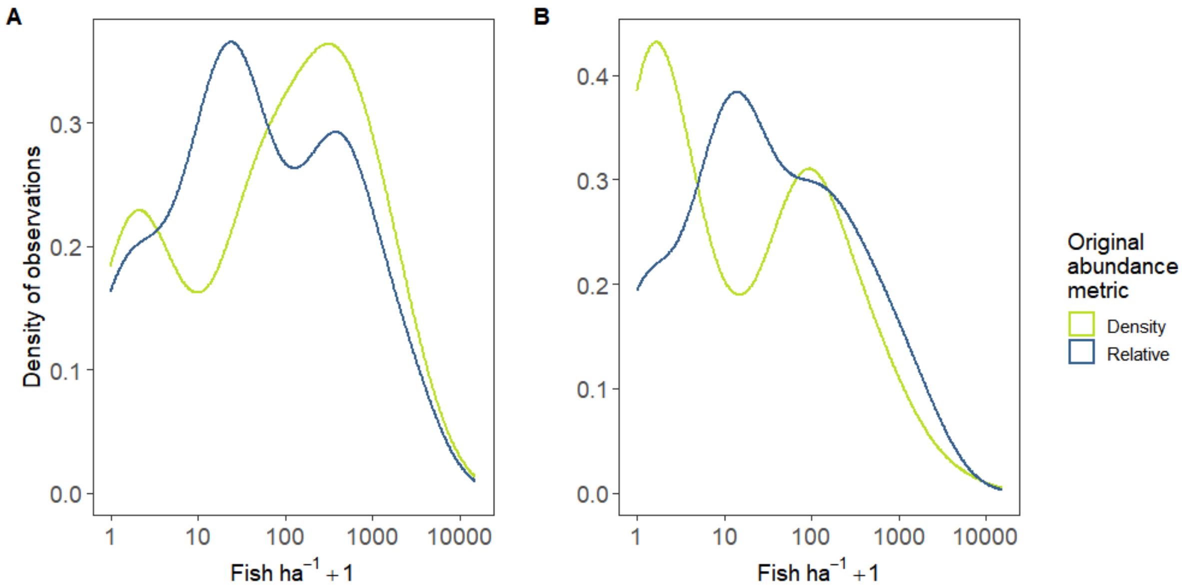

Figure B.1. Comparison of population density estimates at farms (**panel A**) and reference sites (**panel B**) derived from data originally reported as either density or relative abundance. Data reported as relative abundance were converted to density by estimating the area effectively sampled by the specific method employed.

Supplementary Text B.1.

Several recent analyses have highlighted a potential demand-supply gap for farmed seafood (Cai and Leung, 2017; Costello et al., 2020). Cai & Leung (2017) projected a total 28 Mt seafood supply gap by the early 2020s, with the supply growth trend (3% p.a.) for farmed bivalves and other shell molluscs falling well short of the 28% p.a. projected demand growth for those commodities (2.8 of 11.4 Mt met). Seaweed production grew 6.7% p.a. on average in 2000-2017, but did not grow in 2018 (FAO Fisheries and Aquaculture Department, 2020). Policy changes are needed if growing demand for seafood is to be met in a sustainable and ethical manner; Costello et al. (2020) projected that under a future policy reform scenario, bivalve aquaculture would increase 3-fold to 52 Mt live weight by 2050. Wider recognition of ecosystem service provision could help set the stage for policy reform, with improved public perception of non-fed aquaculture products leading to regulatory or financial support for farms that provide such co-benefits. We applied our ecosystem service values to such a scenario (52 Mt bivalves by 2050), with seaweeds assumed to follow the same growth trajectory as bivalves (107 Mt by 2050). The outcome is that by 2030, the marginal production growth (36 Mt bivalves and 74 Mt seaweeds above 2018 levels) could generate a potential value of 35 billion USD annually in the form of regulating and supporting ecosystem services (Table 4). This calculation makes several key assumptions: (i) all further expansion of non-fed aquaculture occurs in waters where nutrient removal is a valuable service, (ii) all new farm footprint area is sited where it will not compete for space with natural habitat structure such as seagrass or reef; (iii) societal and economic values attached to nitrogen removal services in Europe and North America can be applied globally; (iv) farm maintenance and harvesting is done in a way that minimises risks to farm-associated fishes; and (v) expanded production does not displace existing uses of marine and coastal environments that provide ecosystem services (including different services, such as cultural services) of comparable value.

Previous regional and global valuations of nitrogen removal services have varied widely. Ferreira & Bricker (2018) modelled bioextraction rates for each of the major farmed bivalve species in Europe, China and North America using the FARM model framework (Ferreira et al., 2007). They estimated that 635 kt nitrogen is removed annually in those regions, providing a regulating service that would be worth at least 7.7 billion USD within a nutrient offsetting program. Our estimates are in approximate agreement with that value. In contrast, van der Schatte Olivier et al. (2020) applied estimates of nitrogen content to global production statistics, resulting in a value of 49 kt N removed in 2015 (0.4-1.5 billion USD). Their calculations relied heavily on global parameters taken from a small number of empirical sources. This, together with our inclusion of modelled estimates that tend to yield higher nitrogen removal rates than direct measurements, and our decision not to attempt a correction for the non-tissue water content of harvested bivalves (the ‘liquor’), could explain the differing magnitude of global values.

Table B.2. Potential global value of additional nitrogen bioextraction and habitat services provided by a 3-fold growth in non-fed aquaculture by 2050. Monetary values are given with 95% confidence limits around the mean nitrogen removal rate (priced at 32.3 USD kg^{-1}) and ex-vessel value of additional fish produced by aquaculture habitat. The habitat value is conditional on farms using elevated gear placed above primarily unstructured seabed (Model 3, Table S1; Figure 6).

Category	Additional production by 2050 (Mt yr^{-1})	Additional bioextraction (billion USD yr^{-1})	Additional habitat (billion USD yr-1) [a]	Combined additional value (billion USD yr^{-1})
Clams	12.7	4.7 (1.6-11.9)	0 [b]	4.67 (1.63-11.9)
Mussels	4.9	2 (1.2-3.4)	0.16 (-0.19-0.5)	2.19 (1.01-3.88)
Oysters	13.8	11.1 (7-12.9)	5.8 (1.53-10.07)	16.88 (8.55-23.0)
Scallops	4.9	0.66	0.29 (-0.33-0.91) [c]	0.95 (0.33-1.57)
Seaweeds	74.4	7.8 (6.2-10)	2.12 (-1.07-5.3)	9.96 (5.18-15.4)
Sum	**111**	**26 (17-39)**	**8 (0-17)**	**35 (17-56)**

[a] Habitat values are converted from per-area to per-production units according to production intensity data contained within our nutrient removal database.

[b] The fisheries production value of clam farm habitat is under-researched, but available evidence is that fisheries enhancement is close to zero (Smith and McDonald 2009, Brown and Thuesen 2011, Luckenbach et al. 2016).

[c] Scallop farms are data deficient with respect to their role as habitat. Given the similarity to oyster and mussel farms, off-bottom scallop aquaculture likely enhances production, while on-bottom scallop farming may have minimal effect. We assume the habitat value of scallop farming to be 50% of the per-area habitat value of mussel farming.

References for Appendix B

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